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ALASKA DEPARTMENT OF TRANSPORTATION

Analysis of AMHS Fast Vehicle Ferry Wake Wash Predictions-Phase 2 Report; Comparison of the AMHS FVF Expected Wash Characteristics to Existing AMHS Vessels and Cruise Ships

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Date September 2002

Prepared for:
Alaska Department of Transportation
Statewide Research Office
3132 Channel Drive
Juneau, AK 99801-7898

FHWA-AK-RD-02-09

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE & DATES COVERED
	September 2002	Final

4. TITLE AND SUBTITLE
Analysis of AMHS Fast Vehicle Ferry Wake Wash Predictions-Phase 2 Report Comparison of the AMHS FVF Expected Wash Characteristics To Existing AMHS Vessels and Cruise Ships

5. FUNDING NUMBERS

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
FHWA-RD-AK-02-09

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Alaska Department of Transportation and Public Facilities
Statewide Research Office
3131 Channel Drive
Juneau, AK 99801-7898

10. SPONSORING OR MONITORING AGENCY REPORT NUMBER
FHWA-RD-AK-02-09

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This study reviewed the predicted wake wash of the Fast Vehicle Ferry and compared it to wake wash characteristics of existing AMHS vessels and cruise ships operating in Southeast Alaska. Investigators conducted on-scene wake wash measurements of AMHS vessels and cruise ships in the vicinity of Ketchikan, Alaska. Data, conclusions and recommendations are presented.

14. SUBJECT TERMS
Ferry, Fast Vehicle Ferry, Predictions, Wake Wash, Wake Energy, Environmental Impacts, Scour, Water, Water Transportation, Marine Transportation, Maritime Transportation, Water Waves, Hydrologic Phenomena

15. NUMBER OF PAGES
50

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	17. SECURITY CLASSIFICATION OF THIS PAGE	18. SECURITY CLASSIFICATION OF ABSTRACT	19. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Pescribed by ANSI Std. 239-18
298-102

ANALYSIS OF AMHS FAST VEHICLE FERRY WAKE WASH PREDICTIONS

PHASE 2 REPORT

COMPARISON OF THE AMHS FVF EXPECTED WASH CHARACTERISTICS TO EXISTING AMHS VESSELS AND CRUISE SHIPS

Conducted for
ALASKA DEPARTMENT OF TRANSPORTATION & PUBLIC FACILITIES

ALASKA MARINE HIGHWAY SYSTEM

By
Stumbo Associates
Marine Transportation Consultants

September 2002

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ANALYSIS OF AMHS FAST VEHICLE FERRY (FVF) WAKE WASH PREDICTIONS -- PHASE 2 REPORT

EXECUTIVE SUMMARY

PURPOSE

This study compared the predicted wash characteristics of the AMHS FVF to the wash characteristics of existing AMHS vessels and cruise ships operating in Southeast Alaska..

FVF WAKE WASH PREDICTIONS

At the service speed of 32 knots, the range of wash characteristics are predicted to be:

- Height = 47 - 74.2 cm
- Energy = 27,600 - 42, 960 joules/meter

WAKE WASH MEASUREMENT OF AMHS VESSELS AND CRUISE SHIPS

From June 21 through June 23, 2002, the investigators conducted on-scene wake wash measurements of AMHS vessels and cruise ships in the vicinity of Ketchikan, Alaska. The measured wash characteristics of these vessels are shown in the table below, first as measured and then adjusted to a common distance of 300 meters.

Ketchikan Data 6/21-6/23/2002 – Analysis Summary

				As Measured			Adjusted to 300 meters		
Run Number	VESSEL	Speed	Distance Meters	Peiod (Seconds)	Height (meters)	Energy (Joules/meter)	Peiod (Seconds)	Height (meters)	Energy (Joules/meter)
15	COLUMBIA	16.5	960	3.27	0.346	2,507	3.27	0.510	5,443
18	COLUMBIA	18.6	764	4.34	0.523	10,112	4.34	0.715	18,857
17	MATANUSKA	15.5	650	3.64	0.609	9,612	3.64	0.788	16,095
8	NORWEGIAN WIND	12.0	660	4.37	0.496	9,228	4.37	0.646	15,609
12	NORWEGIAN WIND	17.0	607	5.19	0.571	17,218	5.19	0.722	27,545
2a	PRINCE OF WALES	13.0	600	4.14	0.380	4,836	4.14	0.478	7,677
16a	PRINCE OF WALES	15.0	494	3.62	0.551	7,820	3.62	0.651	10,905
19b	PRINCE OF WALES	15.3	147	3.67	0.808	17,247	3.67	0.637	10,720
19a	PRINCE OF WALES	15.0	240	3.90	0.464	6,426	3.90	0.431	5,538
2	STATENDAM	9.0	568	2.94	0.324	1,778	2.94	0.401	2,721
16	SUMMIT	21.7	780	4.36	0.939	32,880	4.36	1.291	62,171
19	SUMMIT	23.0	732	5.32	1.031	58,998	5.32	1.388	106,929
7	SUN PRINCESS	11.0	670	2.80	0.998	15,346	2.80	1.304	26,220
20	TAKU	17.4	530	3.36	0.574	7,312	3.36	0.695	10,685
10	UNIVERSE EXPLORER	9.7	595	2.82	0.119	222	2.82	0.150	351
1	VISION OF THE SEAS	10.9	406	2.55	0.452	2,613	2.55	0.500	3,197
9	VOLENDAM	8.0	390	3.66	0.125	413	3.66	0.137	492
13	VOLENDAM	16.7	746	5.06	0.448	10,090	5.06	0.607	18,519

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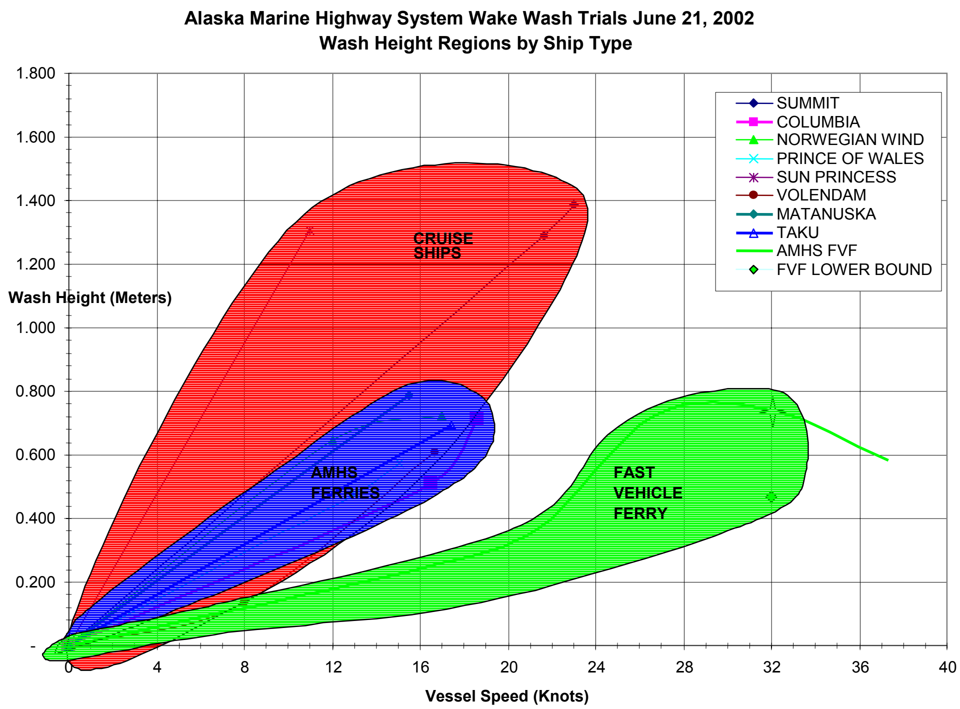
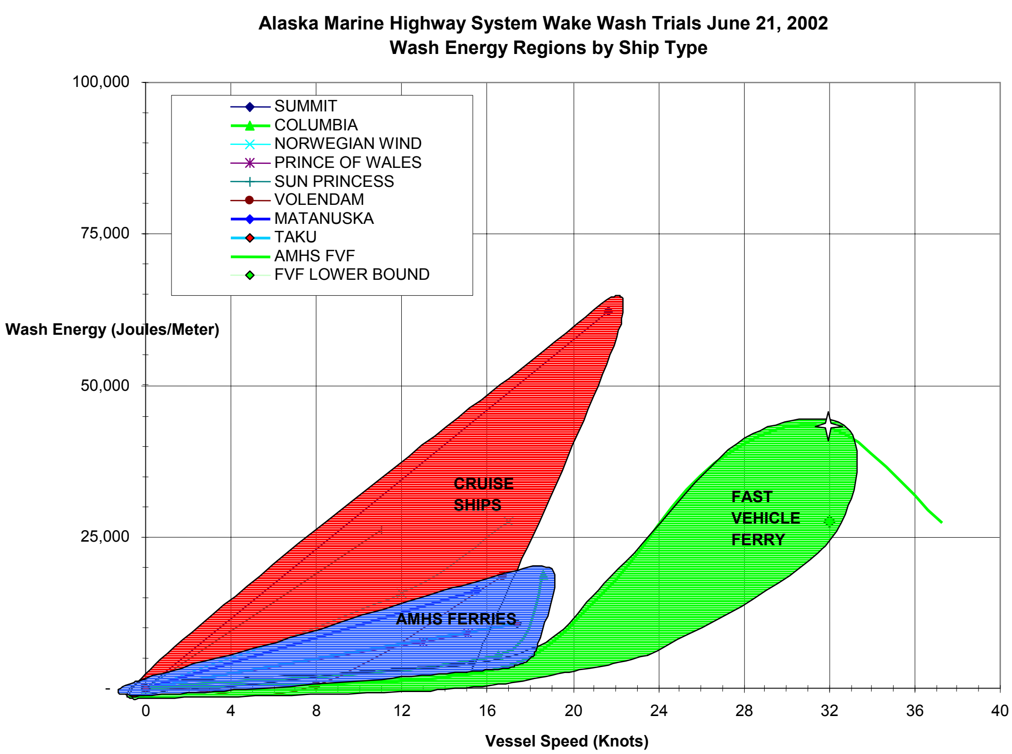
All of the data was then plotted in two graphs – wash height vs. speed and wash energy vs. speed. These plots are shown below with the AMHS ships' plots shown with heavier lines. The regions on the charts representing the various ship types are highlighted





CONCLUSIONS

1. The wake wash from the AMHS Fast Vehicle Ferry will, in all likelihood, be less both in height and energy than cruise ships at service speeds greater than 20 knots.
2. The wake wash height of the AMHS Fast Vehicle Ferry will likely be less than that produced by the largest, fastest conventional AMHS ships.
3. The wake wash energy of the AMHS Fast Vehicle Ferry may be more than that produced by the largest, fastest conventional AMHS ships
4. If there will be a *perceived* wake wash problem with the FVF, it will probably be due to the longer period bow waves produced by the FVF at 32 knots which may persist for longer distances and have a longer run-up on beaches than the shorter period waves of other vessels.

RECOMMENDATIONS

1. Measure the wake wash of the completed FVF during builder's trials with the vessel in a fully loaded condition. Re-examine the comparison with other ship types with the resulting full scale data.
2. Route planning decisions in narrow portions of the Juneau – Sitka route (Olga and Neva Straits, Sergius Narrows) should be made as a result of careful observations of the FVF on the route.
3. Even though the actual FVF wash may prove to be less than predicted and similar to other vessels in the region, public perceptions of fast ferry wash make it prudent to thoroughly document the shoreline conditions of possible sensitive locations along proposed routes.
4. Observe the effect of the FVF wake wash on any floating docks and other structures along the route of the FVF at an early opportunity and determine if undue motions develop.
5. The wash measurements made during builder's or acceptance trials of the first AMHS FVF should include measurements designed to validate the attenuation rate of the longest period waves produced by the vessel.

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September 19, 2002

ANALYSIS OF AMHS FAST VEHICLE FERRY (FVF) WAKE WASH PREDICTIONS
for
ALASKA MARINE HIGHWAY SYSTEM

PHASE 2 REPORT

COMPARISON OF THE AMHS FVF EXPECTED WASH CHARACTERISTICS TO EXISTING AMHS VESSELS AND CRUISE SHIPS

PURPOSE

To compare the predicted wash characteristics of the AMHS FVF to the wash characteristics of existing AMHS vessels and cruise ships operating in Southeast Alaska..

DEFINITION OF TERMS USED IN ANALYSIS

Wake Wash Height: the height, measured in centimeters, from peak to trough, of the highest wave in the series of waves produced by the passing of the measured vessel. Wake wash height is measured or mathematically normalized to a distance of 300 meters perpendicular to the centerline of travel of the vessel. 300 meters is chosen to provide a basis for comparison between various vessels measured under similar circumstances by the investigators.

WakeWash Period: the time, in seconds, for one complete wave cycle to pass a fixed point. The period of the highest wave in the series of waves produced by the passing of the measured vessel is determined by the time difference between the zero crossing of the start of the highest wave and the zero crossing of the start of the next wave in the series.

Wash Energy : Wash energy is calculated from the standard formula in numerous texts (the U.S. Army Corp of Engineers' Shore Protection Manual, Reference 1, for one) of:

$$E = \frac{\gamma \cdot g \cdot H^2 \cdot L}{8}$$

where γ is the density of water, g is the acceleration due to gravity, H is the wash height, and L is the wash wavelength. The term for wavelength in this formula is to be replaced by a function of wash period from the relationship given below:

$$L = \frac{g \cdot T^2}{2 \cdot \pi}$$

resulting in the following equation:

$$E = \frac{\gamma \cdot g^2 \cdot H^2 \cdot T^2}{16 \cdot \pi}$$

In metric units, with H in meters and T in seconds, this formula reduces to:

$$E = 1961 \cdot H^2 \cdot T^2$$

with the output expressed in joules per meter of wave front.

Length Froude Number: a convenient non-dimensional ratio for use in comparisons is given by:

$$F_{nl} = \frac{V}{\sqrt{g \cdot (LWL)}}$$

where V is vessel speed, g is the gravitational constant, and LWL is the vessel waterline length.

FVF WAKE WASH PREDICTIONS

Reference 2 provided data from the Nigel Gee and Associates (NGA) tow tank tests of a 70 meter FVF which predicted wake wash characteristics of the proposed hull form for the AMHS FVF. It has been the investigators' practice to measure wake wash at 300 meters from the sailing line or convert the measurements to that distance in order to have a convenient common basis of comparison for all vessels. NGA provided data at 304.8 meters (1000 feet) and the data at that distance is not discernibly different than for 300 meters. This data has been graphed and was presented in the Phase 1 report of this investigation (Reference 3). Also, in Phase 1, lower bounds for predicted wave height and energy were established based on data from other investigations and measurements. Figures 1 and 2 from that report are repeated below with the data points for the service speed of 32 knots noted.

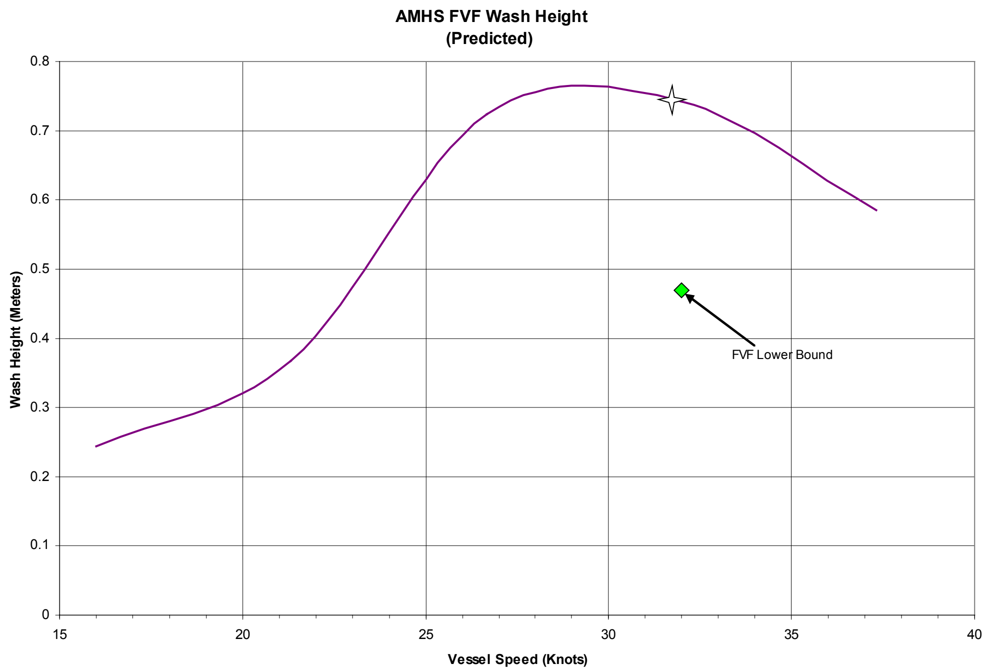

Figure 1. NGA 70 Predicted Wash Height

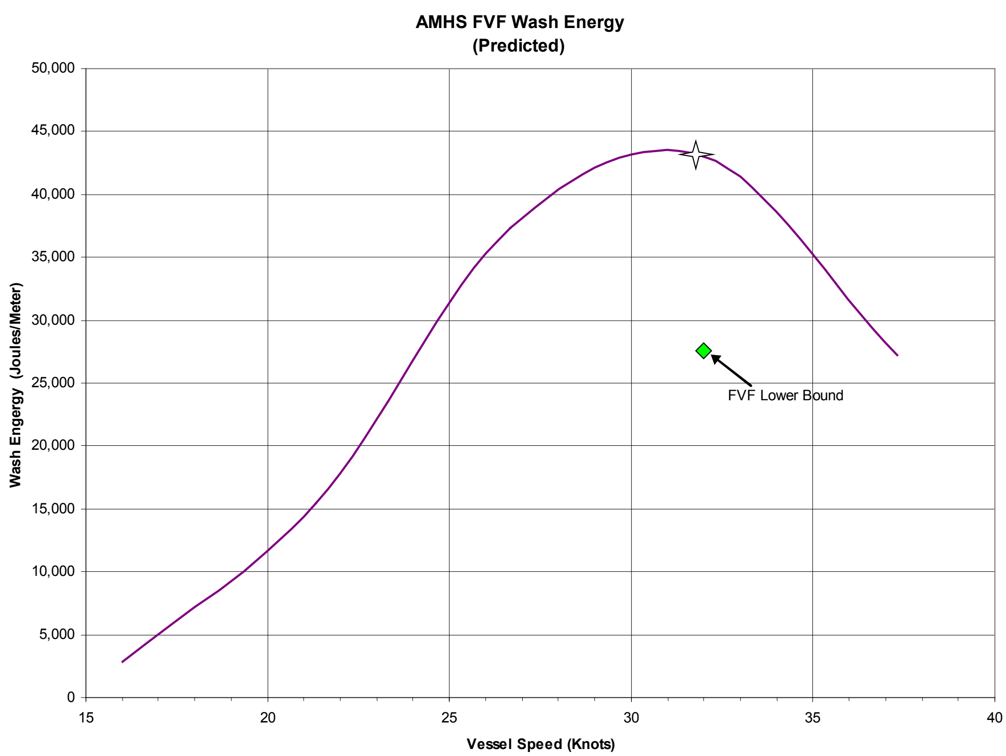

Figure 2. NGA 70 Predicted Wash Energy

At the service speed of 32 knots, the range of wash characteristics are predicted to be:

- H = 47 - 74.2 cm
- E = 27,600 - 42, 960 joules/meter

WAKE WASH MEASUREMENT OF AMHS VESSELS AND CRUISE SHIPS

From June 21 through June 23, 2002, the investigators conducted on-scene wake wash measurements of AMHS vessels and cruise ships in the vicinity of Ketchikan, Alaska. Locations were chosen in deep water (> 200 feet) both north and south of (or in) Tongass Narrows in order to measure the maximum number of vessels in the time permitted, and also to measure each vessel at two or more speeds if possible. These locations are shown on the charts below (Figures 3 and 4). Each site is marked by a point "A" at one end of a line approximately 1000 meters long.

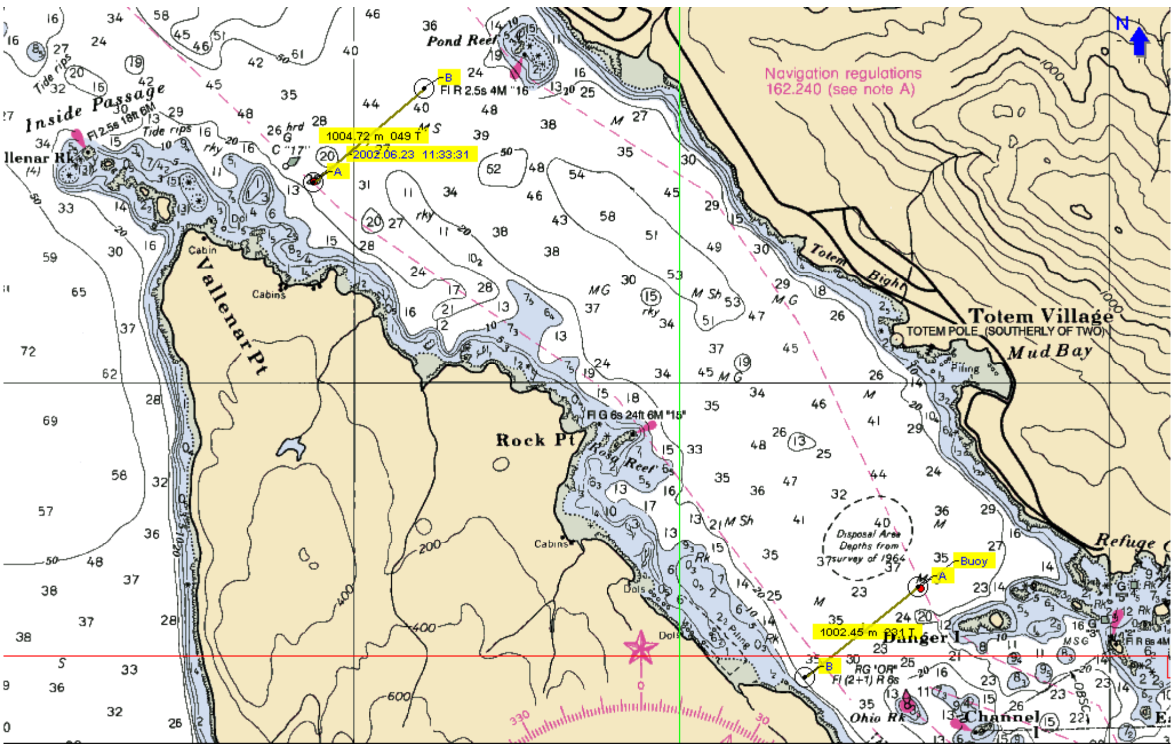

Figure 3. Wash Measurement Sites in Northern Tongass Narrows

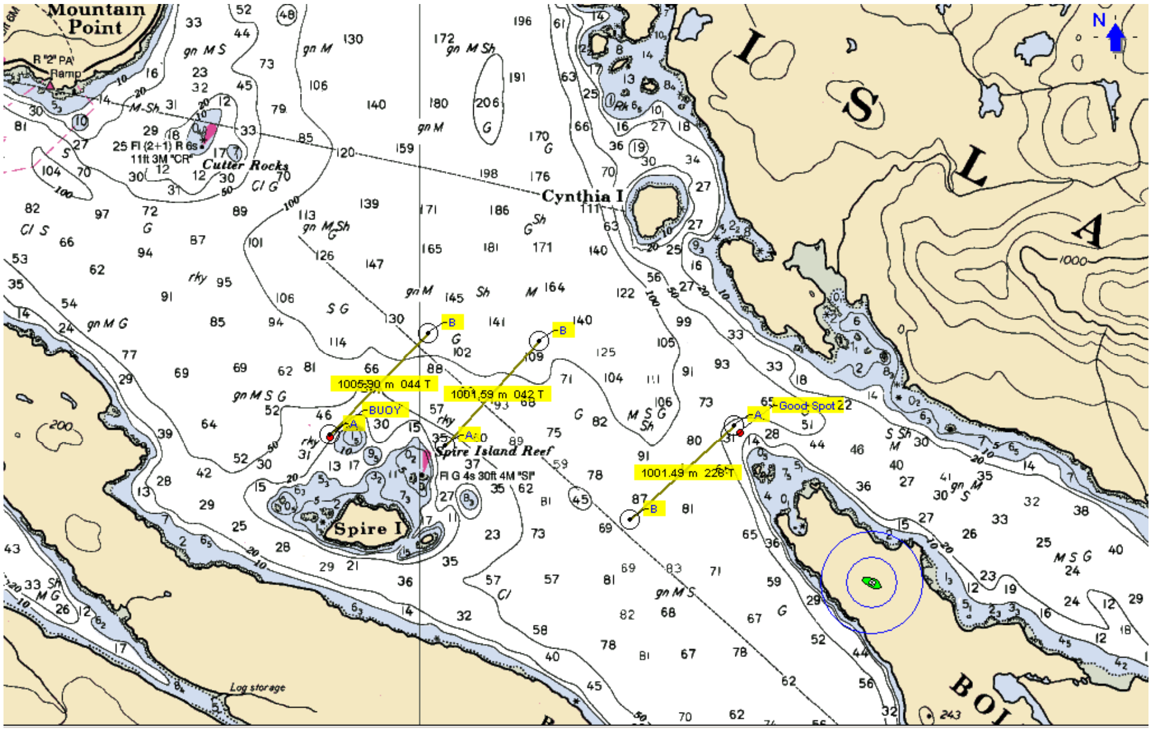

Figure 4. Wash Measurement Sites South of Tongass Narrows at Spire and Bold Islands

Wave heights and periods of vessel wash were measured using a submerged instrument package that measures pressure 4 times per second and records data to a HEX file in computer memory in the package. Speeds were obtained by radio communication with each vessel at the time the vessel passed the wave buoy marker. The instrument package is anchored to the bottom, typically in 200 feet of water, and suspended from a buoy that is held 6 to 10 feet below the surface of the water by a taut line to the anchor. A marker buoy on the surface is used for location and recovery. This test setup is depicted in the Figure 5:

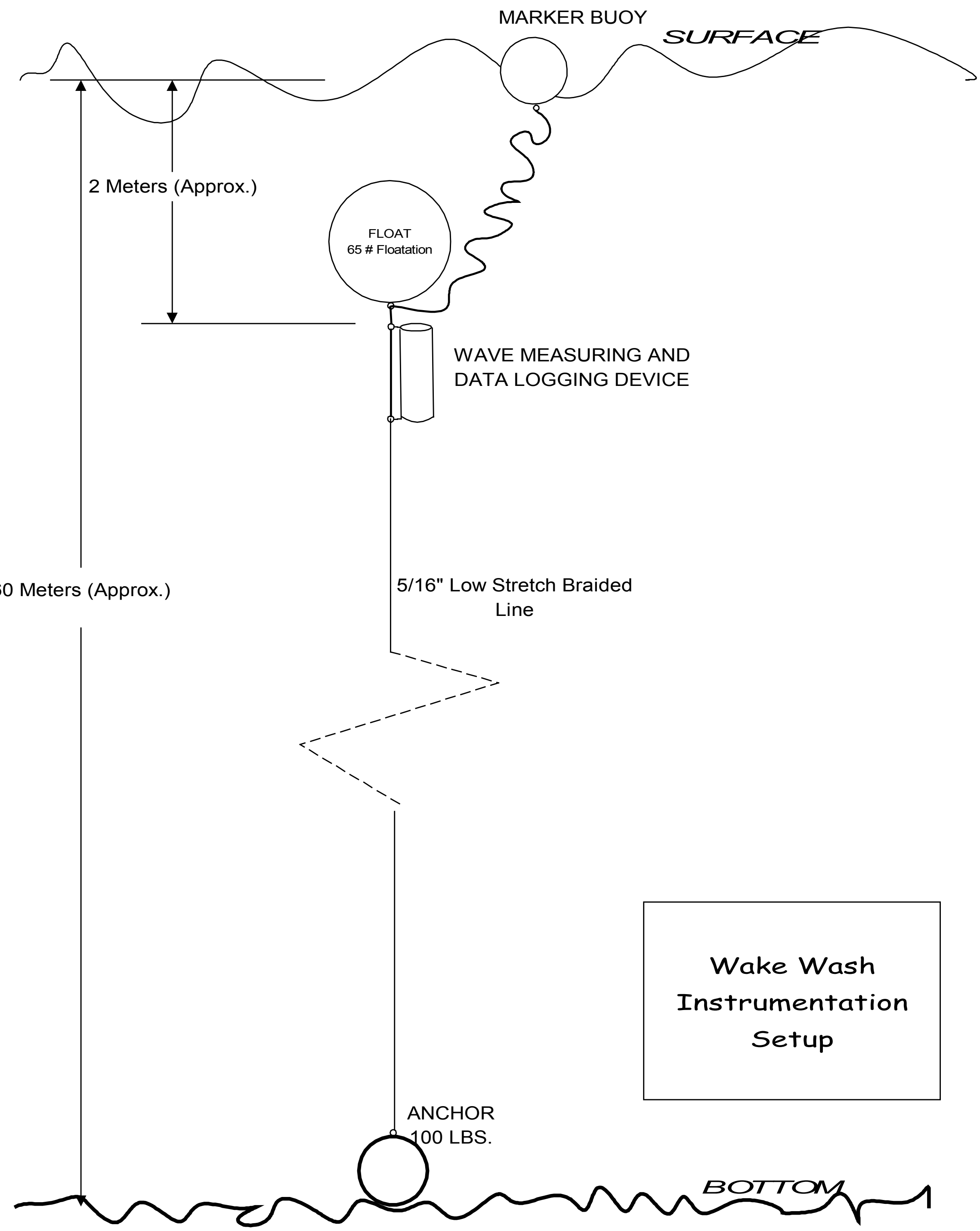

Figure 5. Wake Wash Instrumentation Setup

After data download, custom software converts the pressure readings to wave heights as a function of time, enabling measurements and plots to be made of wave patterns passing over the buoy.

PROCEDURE

To gather data, the vessels passed the deployed instruments on their normal course through the area. The instrument deployment sites were chosen so that vessels would pass within 1000 meters. The actual distance was measured using a laser rangefinder. Speeds were determined by hailing each vessel on VHF radio and getting a reply of the vessel's speed at the time of passing the instruments. Each passage's data was normalized to a distance off centerline of travel of 300 meters (~1000 feet) to enable valid comparisons. Plots were then developed of wash height vs. speed and wash energy vs. speed.

VESSELS MEASURED

Table 1. Alaska Marine Highway System Ships (and PRINCE OF WALES)

NAME	LENGTH (meters)	Est. LWL (meters)	PAX	VEHICLES (std. autos)	SERVICE SPEED (knots)	SPEED MEASURED
COLUMBIA	127.4	121	625	134	17.3	16.5, 18.6
MATANUSKA	124.4	118.1	500	88	16.5	15.5
TAKU	107.3	102	450	69	16.5	17.4
PRINCE OF WALES	60	53.5	150	30	15	13, 15, 15.3

Figure 6. M/V COLUMBIA

Figure 7. M/V MATANUSKA

Figure 8. M/V TAKU

Figure 9. M/V PRINCE OF WALES

Table 2. Cruise Ships

NAME	LENGTH (meters)	Est. LWL (meters)	PAX	CREW	SERVICE SPEED (knots)	SPEED MEASURED
SUMMIT	294.1	279.4	1950		24	21.7, 23
VISION OF THE SEAS	278.9	265	2435		22	10.9
SUN PRINCESS	260.9	247.9	1950	830	21	11
VOLENDAM	238	226	1440		23	8, 16.7
NORWEGIAN WIND	229.8	218.3	1748	689	18	12, 17
STATENDAM	219.4	208.5	1266	602	22	9
UNIVERSE EXPLORER	188	178.7	737		18	9.7

Note: It was not possible to obtain measurements of the wake wash of all of the cruise ships at service speed. Several were slowing to time their entrance into Ketchikan or had set a slower speed for their next destination because their scheduled arrival did not require full service speed. Sufficient data was gathered at service speeds, however, to be representative of the ship type.

Figure 10. MS SUMMIT

Figure 11. MS VISION OF THE SEAS

Figure 12. MS SUN PRINCESS

Figure 13. MS VOLENDAM

Figure 14. MS NORWEGIAN WIND

Figure 15. MS STATENDAM

Figure 16. MS UNIVERSE EXPLORER

RESULTS

In the analysis, the height, period and energy of each wave in the wave train of each vessel tested was calculated and a graph produced for all runs. These graphs are included in this report in the 'Individual Runs' tab. The summary data for Run 19b is also included as a sample of more detailed numerical data. If needed, such data can be produced for each run as well as detailed data points that are summarized in the graphs. Representative graphs of wave trains are shown below for the M/V COLUMBIA and the MS SUMMIT. In these representative graphs, the tallest wave in the train has been highlighted in yellow and the graphs are presented for the actual distance off centerline of travel, i.e., the height and energy has not yet been adjusted to a common 300 meters.

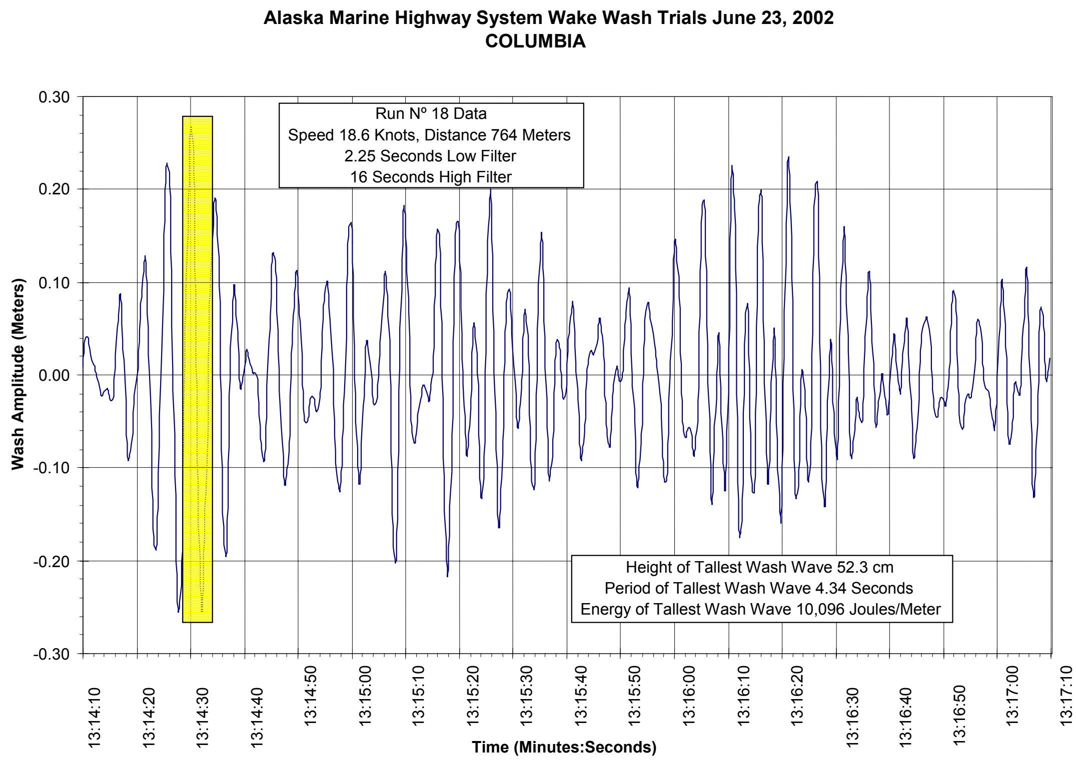

Figure 17. Run No. 18, M/V COLUMBIA

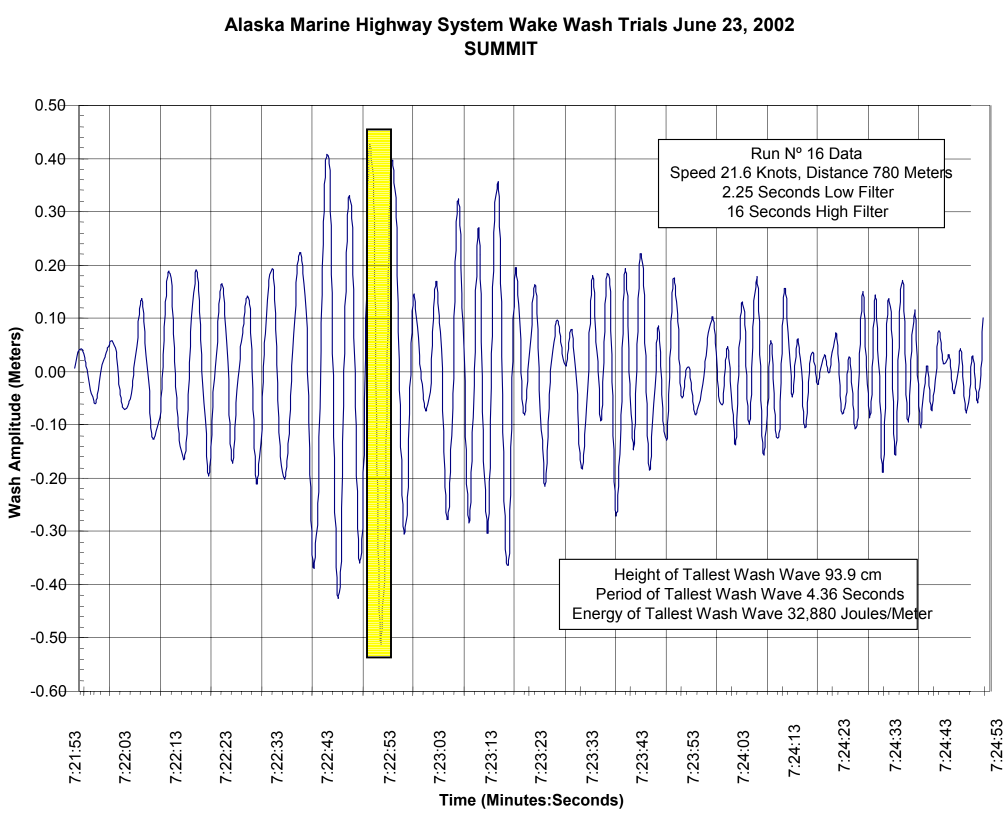

Figure 18. Run No. 16, MS SUMMIT

The measured wash characteristics of the vessels measured in June 2002 are shown in Table 1 below, first as measured and then adjusted by the inverse cube root rule to a common distance of 300 meters.

Ketchikan Data 6/21-6/23/2002 – Analysis Summary

				As Measured			Adjusted to 300 meters		
Run Number	VESSEL	Speed	Distance Meters	Peiod (Seconds)	Height (meters)	Energy (Joules/meter)	Peiod (Seconds)	Height (meters)	Energy (Joules/meter)
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16a	PRINCE OF WALES	15.0	494	3.62	0.551	7,820	3.62	0.651	10,905
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16	SUMMIT	21.7	780	4.36	0.939	32,880	4.36	1.291	62,171
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1	VISION OF THE SEAS	10.9	406	2.55	0.452	2,613	2.55	0.500	3,197
9	VOLENDAM	8.0	390	3.66	0.125	413	3.66	0.137	492
13	VOLENDAM	16.7	746	5.06	0.448	10,090	5.06	0.607	18,519

Table 3. Analysis Summary

The data was then plotted in two graphs – wash height vs. speed and wash energy vs. speed. These plots are shown in Figures 19 and 20 below with the AMHS ships' plots shown with heavier lines. Where the height or energy curve is represented as a straight line, it is only because a single speed was measured for that vessel. Measurement at multiple speeds would have resulted in defining a curve for the characteristics.

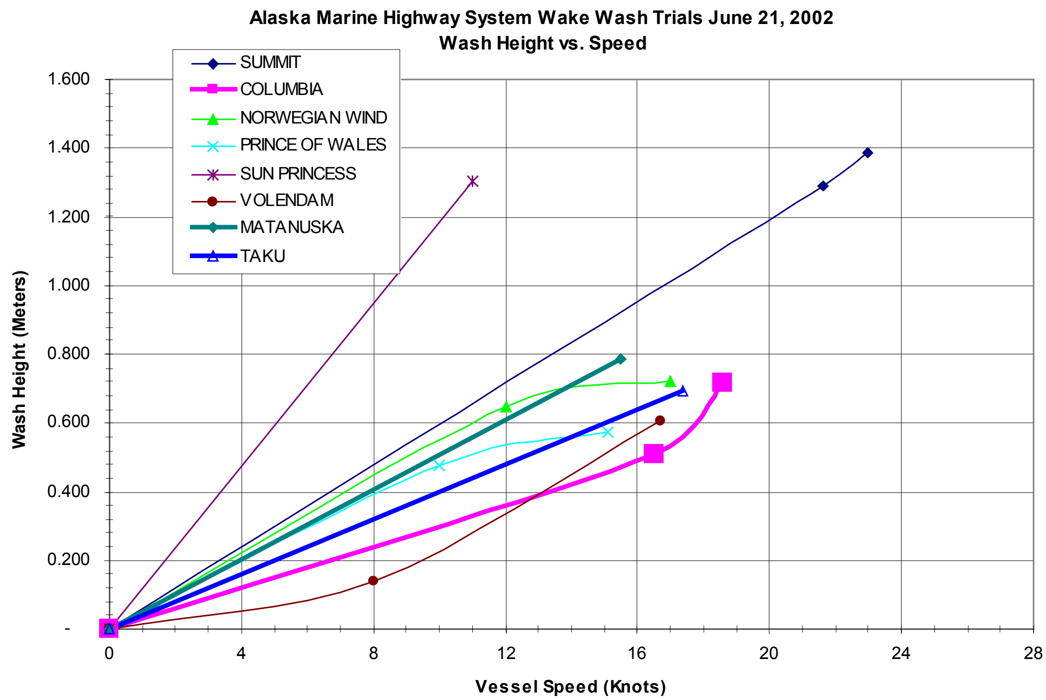


Figure 19. Height vs. Speed of Measured Vessels

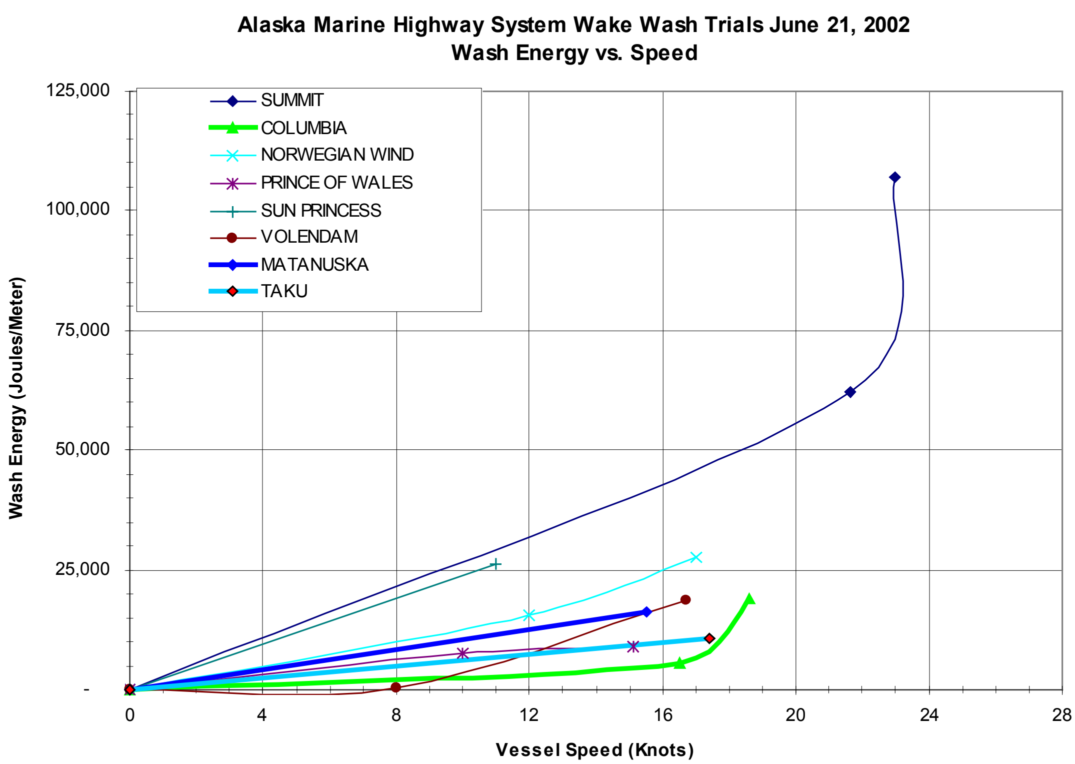


Figure 20. Energy vs. Speed of Measured Vessels

COMPARISONS OF PRESENT VESSELS WITH AMHS FVF PREDICTED WASH

The AMHS FVF wake wash prediction curves from Figures 1 and 2 were added to the charts to plot all characteristics on the same chart:

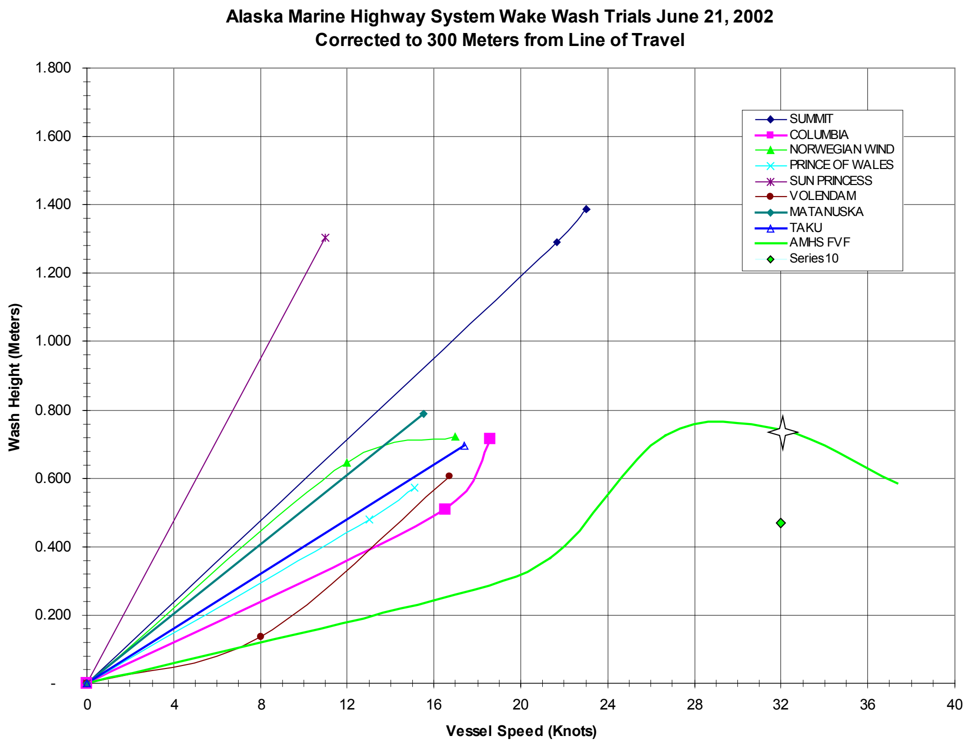


Figure 21. Comparison of Ferries and Cruise Ships to AMHS FVF (Height vs. Speed)

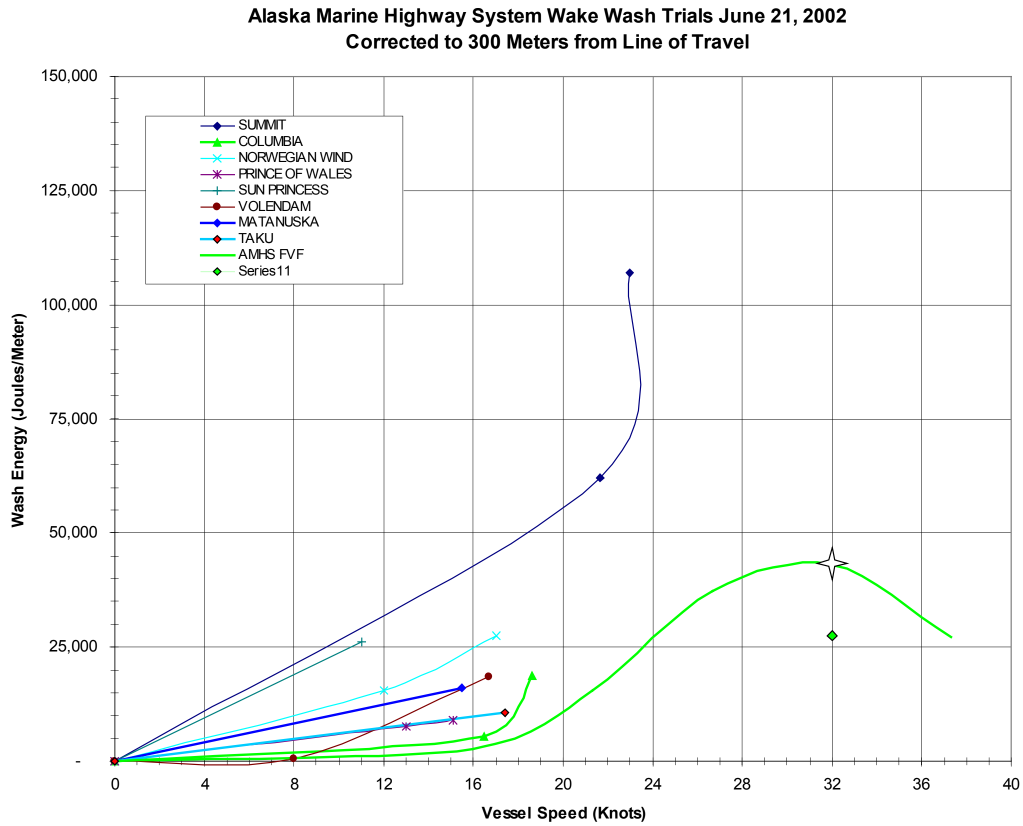


Figure 22. Comparison of Ferries and Cruise Ships to AMHS FVF (Energy vs. Speed)

Several observations can be made in these last two graphs:

- The maximum wave height for any measured existing AMHS vessel is 0.715 meters (~ 28 inches). This observation includes the PRINCE OF WALES.
- The maximum wave height for cruise ships is 1.388 meters (~ 55 inches). The data from cruise ships measured at slower speed trends toward the same heights for those capable of service speeds in excess of 20 knots. This is true with the exception of VOLENDAM.
- Based on the FVF predictions, the FVF may have a lower wash height than existing AMHS ferries but will probably exceed existing AMHS ferries in wash energy due to the longer wave period of the FVF.
- The FVF's predicted wash height and energy is substantially lower than that of cruise ships with service speeds above 20 knots.

These observations are perhaps clearer if the regions on the charts representing the various ship types are highlighted. In the charts below, Figures 23 and 24 are repeated but with these regions highlighted.

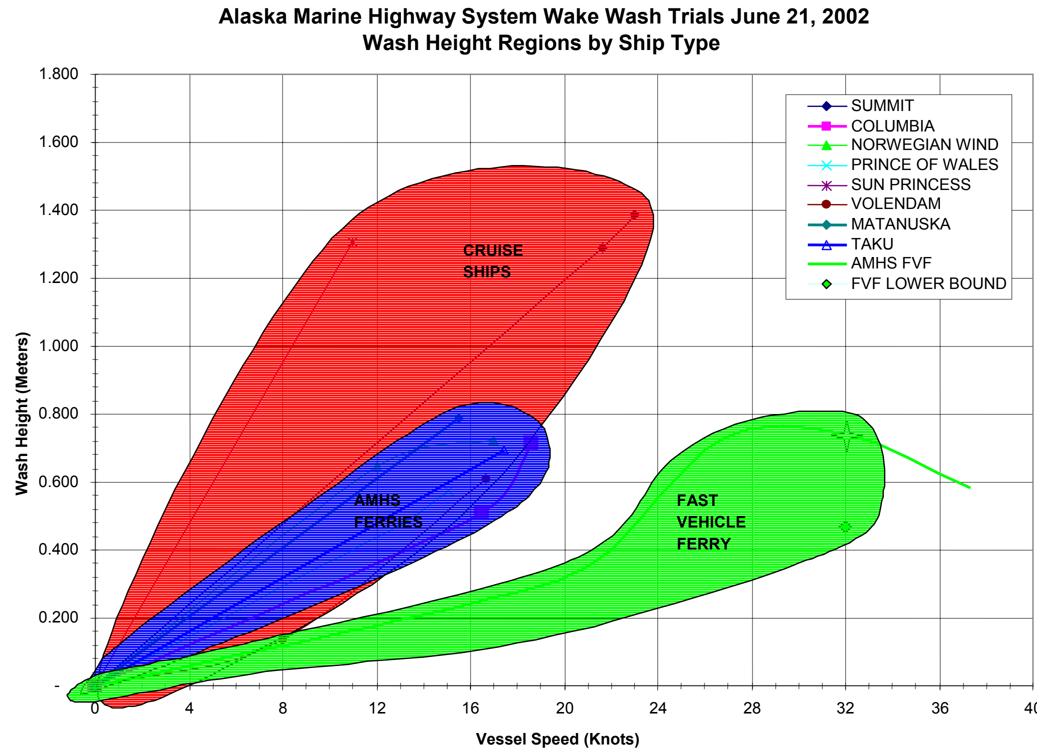


Figure 23. Wash Regions by Ship Type (Height vs. Speed)

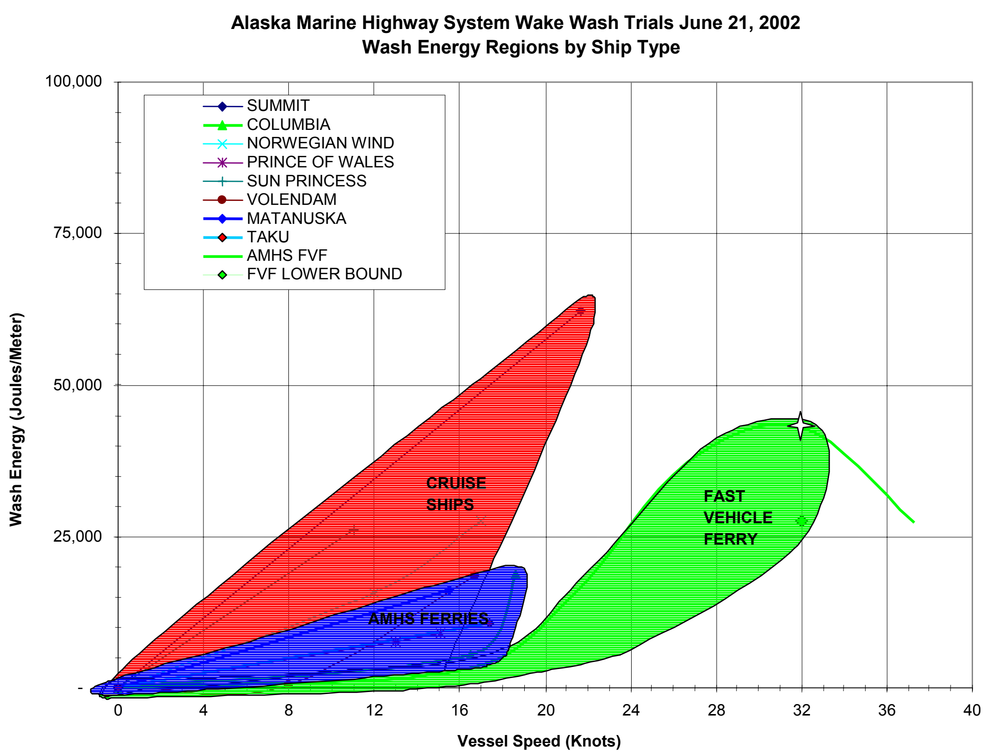


Figure 24. Wash Regions by Ship Type (Energy vs. Speed)

DISCUSSION OF RESULTS

In analyzing the data from measured vessels, the investigators have consistently used the inverse cube root rule (References 4, 5 and 6) to account for wave attenuation with distance. All measurements were adjusted to a common distance off centerline of travel of 300 meters (~ 1000 feet). The formula for this adjustment is:

$$\frac{H_2}{H_1} = \sqrt[3]{\frac{d_1}{d_2}}$$

In discussions with other investigators of wake wash (mostly international) and review of the current literature, we find that theories have been presented that the attenuation rate for the longer period waves produced by large fast ferries <u>may</u> be less than that calculated by the inverse cube root rule. No definitive proof or disproof of this possibility has yet been published. If a lesser rate of attenuation proves to be true:

- The FVF wake wash predictions of Reference 2 may be lower than the wake wash of the actual vessel.
- The wash of the FVF (and some large cruise ships) may affect shorelines and structures at greater distances than anticipated due to higher "persistence" of longer period waves.

Consequently, it is recommended that the wash measurements made during builder's or acceptance trials of the first AMHS FVF include measurements designed to validate the attenuation rate of the longest period waves produced by the vessel.

CONCLUSIONS

5. The wake wash from the AMHS Fast Vehicle Ferry will, in all likelihood, be less both in height and energy than cruise ships at service speeds greater than 20 knots.
6. The wake wash height of the AMHS Fast Vehicle Ferry will likely be <u>less</u> than that produced by the largest, fastest conventional AMHS ships.
7. The wake wash energy of the AMHS Fast Vehicle Ferry may be <u>more</u> than that produced by the largest, fastest conventional AMHS ships
8. If there will be a *perceived* wake wash problem with the FVF, it will probably be due to the longer period bow waves produced by the FVF at 32 knots which may persist for longer distances and have a longer run-up on beaches than the shorter period waves of other vessels.

RECOMMENDATIONS

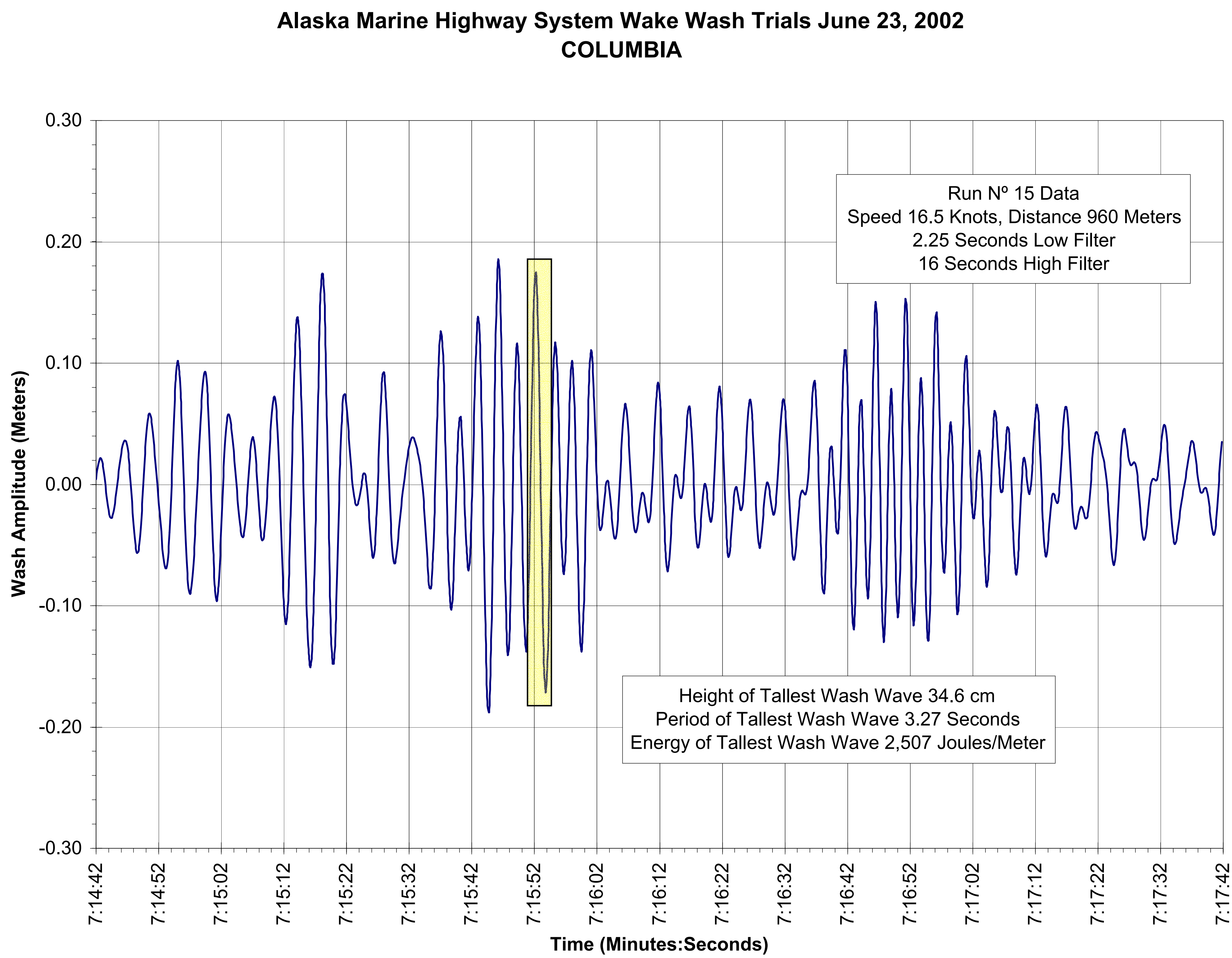
6. Measure the wake wash of the completed FVF during builder's trials with the vessel in a fully loaded condition. Re-examine the comparison with other ship types with the resulting full scale data.

7. Route planning decisions in narrow portions of the Juneau – Sitka route (Olga and Neva Straits, Sergius Narrows) should be made as a result of careful observations of the FVF on the route.
8. Even though the actual FVF wash may prove to be less than predicted and similar to other vessels in the region, public perceptions of fast ferry wash make it prudent to thoroughly document the shoreline conditions of possible sensitive locations along proposed routes.
9. Observe the effect of the FVF wake wash on any floating docks and other structures along the route of the FVF at an early opportunity and determine if undue motions develop.
10. The wash measurements made during builder's or acceptance trials of the first AMHS FVF should include measurements designed to validate the attenuation rate of the longest period waves produced by the vessel.

REFERENCES:

1. **"Shore Protection Manual",** Coastal Engineering Research Center, Dept. of the Army, Waterways Experiment Station, Corps of Engineers, 1984.
2. **"Alaska Marine Highways 70 m Car Passenger Ferry, Wave Signature"**; Nigel Gee and Associates; undated.
3. **Stumbo, Stan, et. al.,** "Analysis of AMHS Fast Vehicle Ferry (FVF) Wake Wash Predictions-Phase 1 Report Comparison of the AMHS FVF Expected Wash Characteristics Against Measured Vessels and Past Studies", FHWA-AK-RD-02-04, June 27, 2002.
4. **Lord Kelvin (Sir William Thompson)**, "On Ship Waves", *Proceedings, Institute of Mechanical Engineers,* London, U.K., 1887.
5. **Havelock, T.H.,** "The Propagation of Groups of Waves in Dispersive Media, with Application to Waves on Water Produced by a Traveling Disturbance", *Proceedings,* Royal Society of London, London, England, Series A, 1908, pp 398-430.
6. **Havelock, T.H.,** "The Propagation of Disturbances in Dispersive Media", Cambridge University Press, Cambridge, England, 1914.

Appendix A


Alaska Marine Highway System Wake Wash Trials June 23, 2002
COLUMBIA
Run Nº 15 Data
Speed 16.5 Knots, Distance 960 Meters
2.25 Seconds Low Filter
16 Seconds High Filter
Height of Tallest Wash Wave 34.6 cm
Period of Tallest Wash Wave 3.27 Seconds
Energy of Tallest Wash Wave 2,507 Joules/Meter
Wash Amplitude (Meters)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
Time (Minutes:Seconds)
7:14:42
7:14:52
7:15:02
7:15:12
7:15:22
7:15:32
7:15:42
7:15:52
7:16:02
7:16:12
7:16:22
7:16:32
7:16:42
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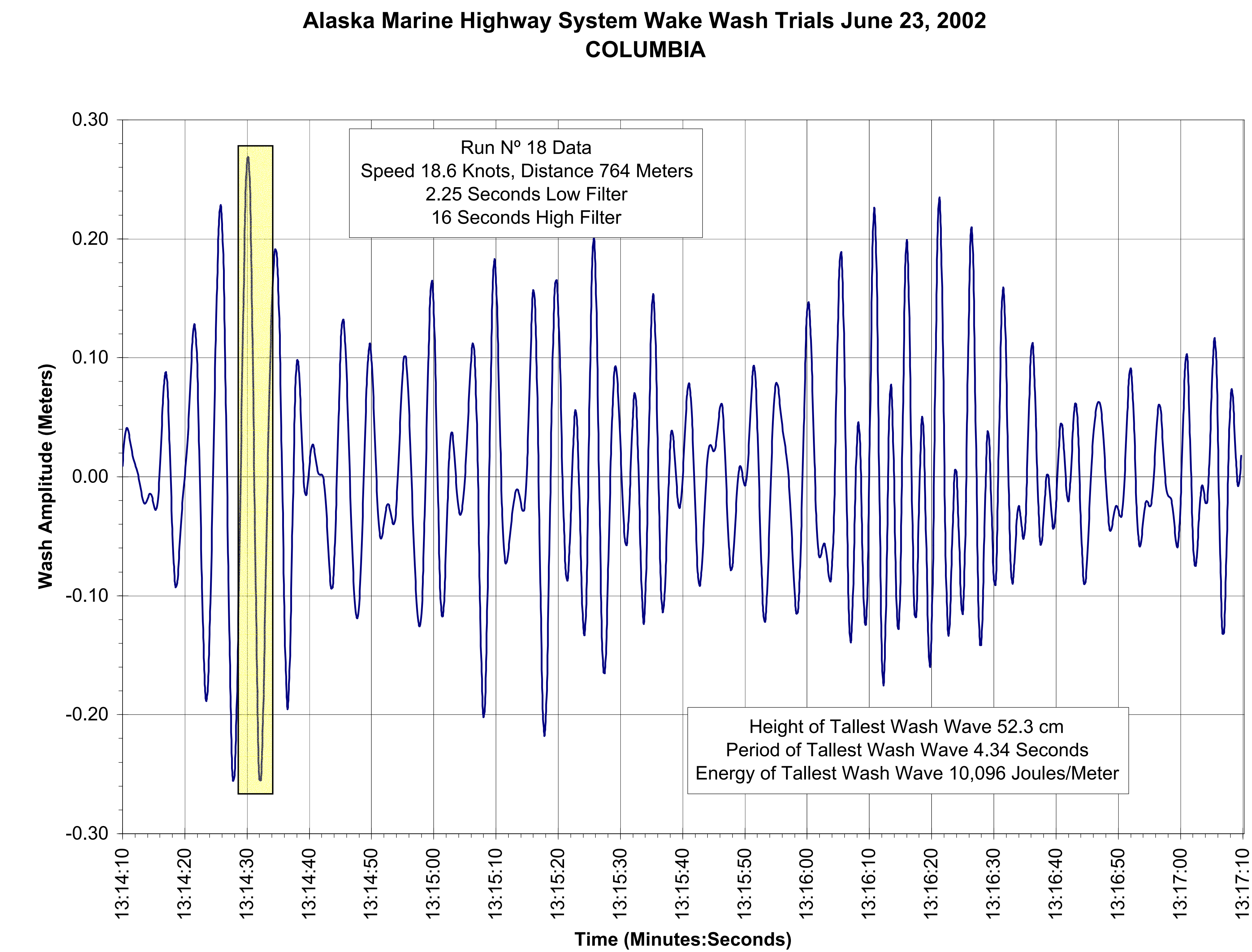
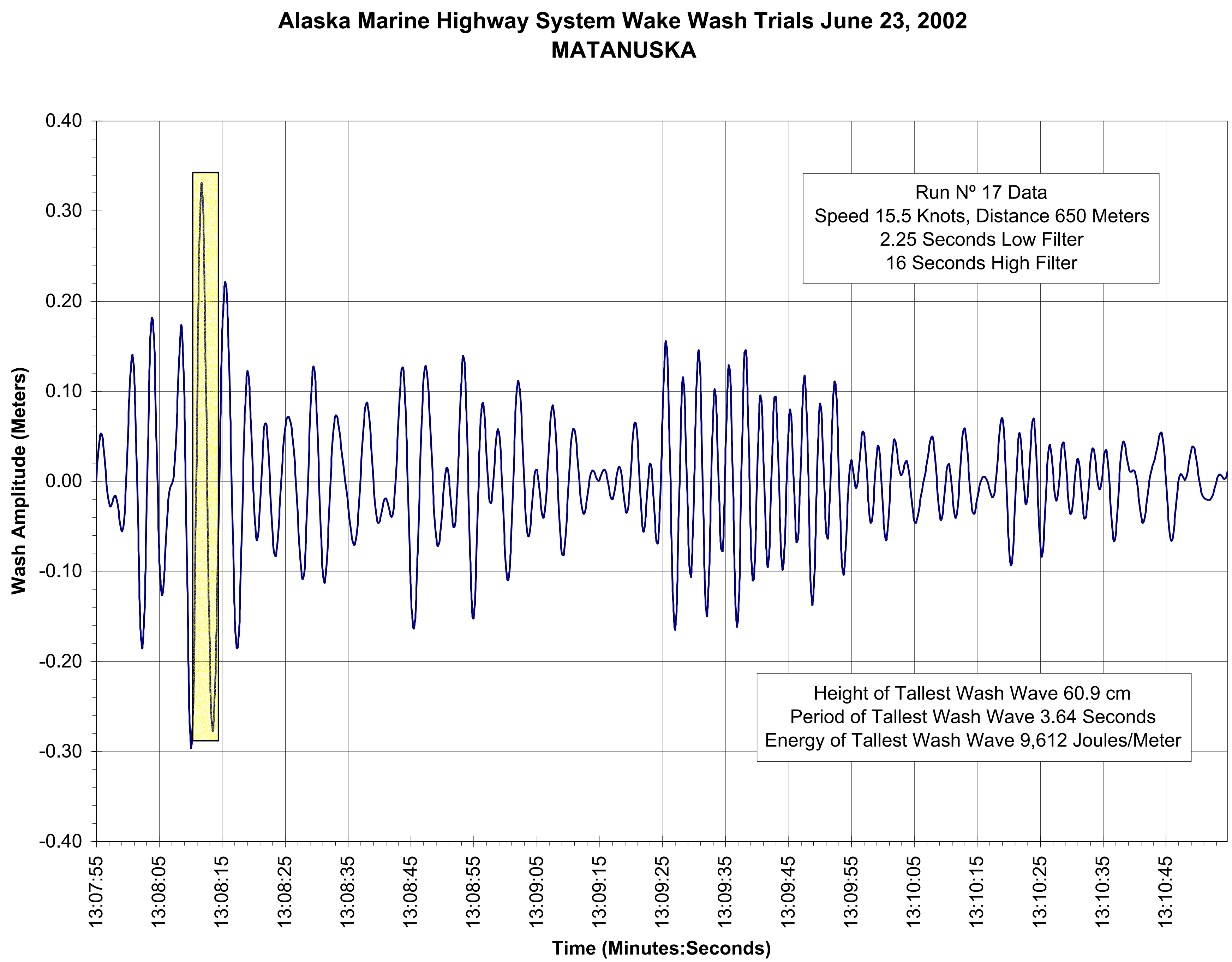
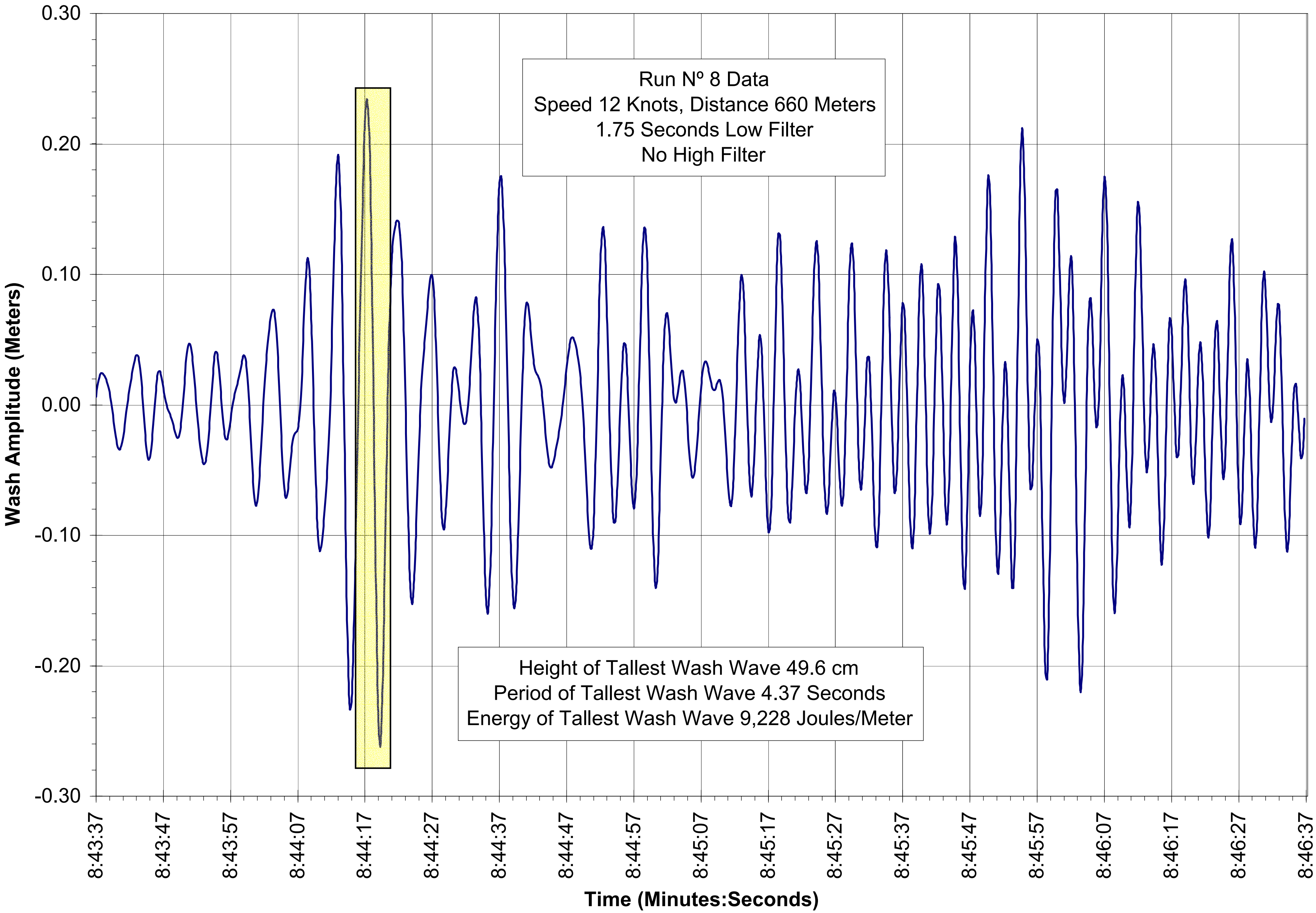
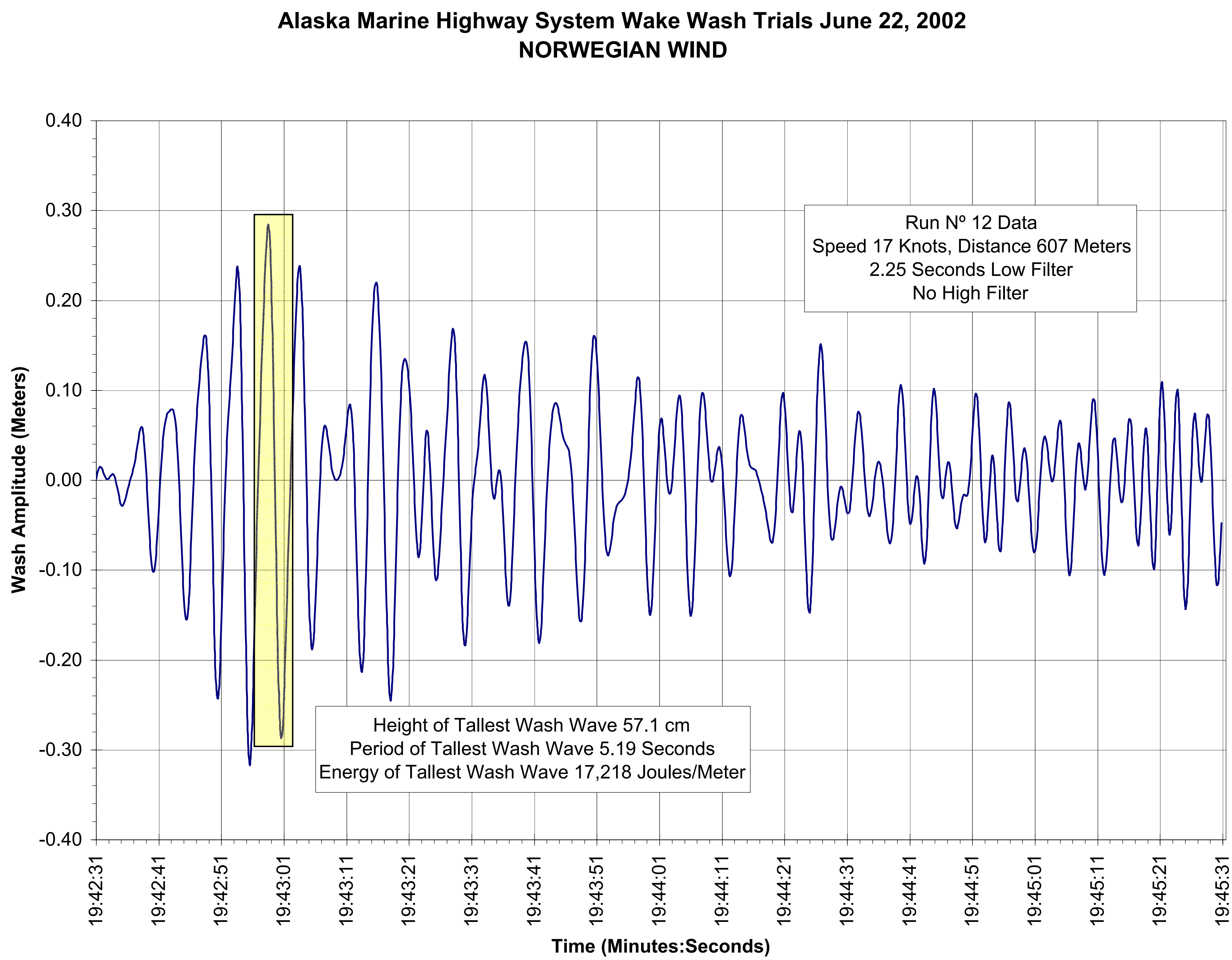
7:17:02
7:17:12
7:17:22
7:17:32
7:17:42


Alaska Marine Highway System Wake Wash Trials June 23, 2002
COLUMBIA
Run Nº 18 Data
Speed 18.6 Knots, Distance 764 Meters
2.25 Seconds Low Filter
16 Seconds High Filter
Height of Tallest Wash Wave 52.3 cm
Period of Tallest Wash Wave 4.34 Seconds
Energy of Tallest Wash Wave 10,096 Joules/Meter
Wash Amplitude (Meters)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
Time (Minutes:Seconds)
13:14:10
13:14:20
13:14:30
13:14:40
13:14:50
13:15:00
13:15:10
13:15:20
13:15:30
13:15:40
13:15:50
13:16:00
13:16:10
13:16:20
13:16:30
13:16:40
13:16:50
13:17:00
13:17:10

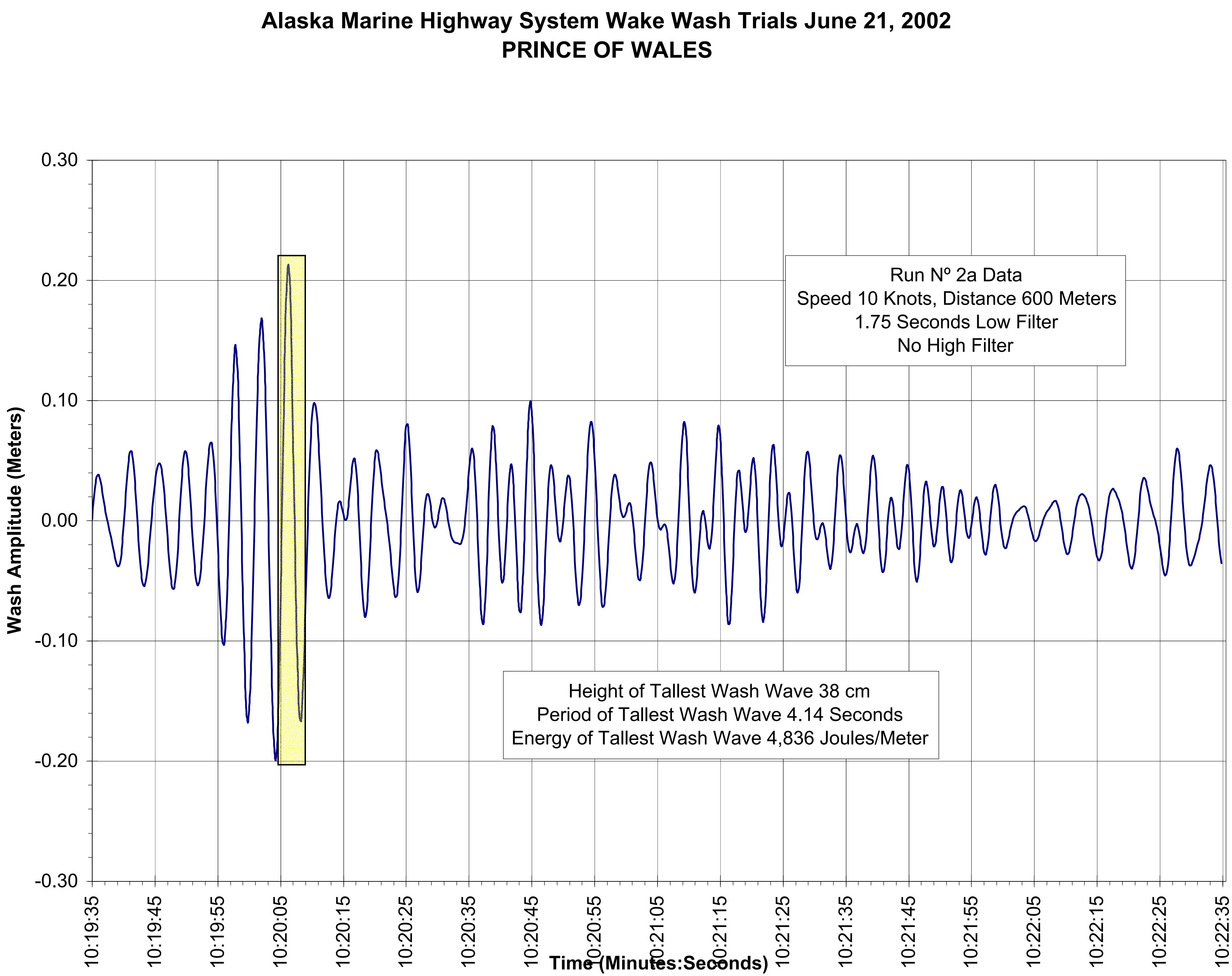

Alaska Marine Highway System Wake Wash Trials June 23, 2002
MATANUSKA
Run Nº 17 Data
Speed 15.5 Knots, Distance 650 Meters
2.25 Seconds Low Filter
16 Seconds High Filter
Height of Tallest Wash Wave 60.9 cm
Period of Tallest Wash Wave 3.64 Seconds
Energy of Tallest Wash Wave 9,612 Joules/Meter
Wash Amplitude (Meters)
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
13:07:55
13:08:05
13:08:15
13:08:25
13:08:35
13:08:45
13:08:55
13:09:05
13:09:15
13:09:25
13:09:35
13:09:45
13:09:55
13:10:05
13:10:15
13:10:25
13:10:35
13:10:45
Time (Minutes:Seconds)

Alaska Marine Highway System Wake Wash Trials June 22, 2002
NORWEGIAN WIND





Alaska Marine Highway System Wake Wash Trials June 22, 2002
NORWEGIAN WIND
Run Nº 12 Data
Speed 17 Knots, Distance 607 Meters
2.25 Seconds Low Filter
No High Filter
Height of Tallest Wash Wave 57.1 cm
Period of Tallest Wash Wave 5.19 Seconds
Energy of Tallest Wash Wave 17,218 Joules/Meter
Wash Amplitude (Meters)
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
19:42:31
19:42:41
19:42:51
19:43:01
19:43:11
19:43:21
19:43:31
19:43:41
19:43:51
19:44:01
19:44:11
19:44:21
19:44:31
19:44:41
19:44:51
19:45:01
19:45:11
19:45:21
19:45:31
Time (Minutes:Seconds)


Alaska Marine Highway System Wake Wash Trials June 21, 2002
PRINCE OF WALES
Run Nº 2a Data
Speed 10 Knots, Distance 600 Meters
1.75 Seconds Low Filter
No High Filter
Height of Tallest Wash Wave 38 cm
Period of Tallest Wash Wave 4.14 Seconds
Energy of Tallest Wash Wave 4,836 Joules/Meter
Wash Amplitude (Meters)
Time (Minutes:Seconds)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
10:19:35
10:19:45
10:19:55
10:20:05
10:20:15
10:20:25
10:20:35
10:20:45
10:20:55
10:21:05
10:21:15
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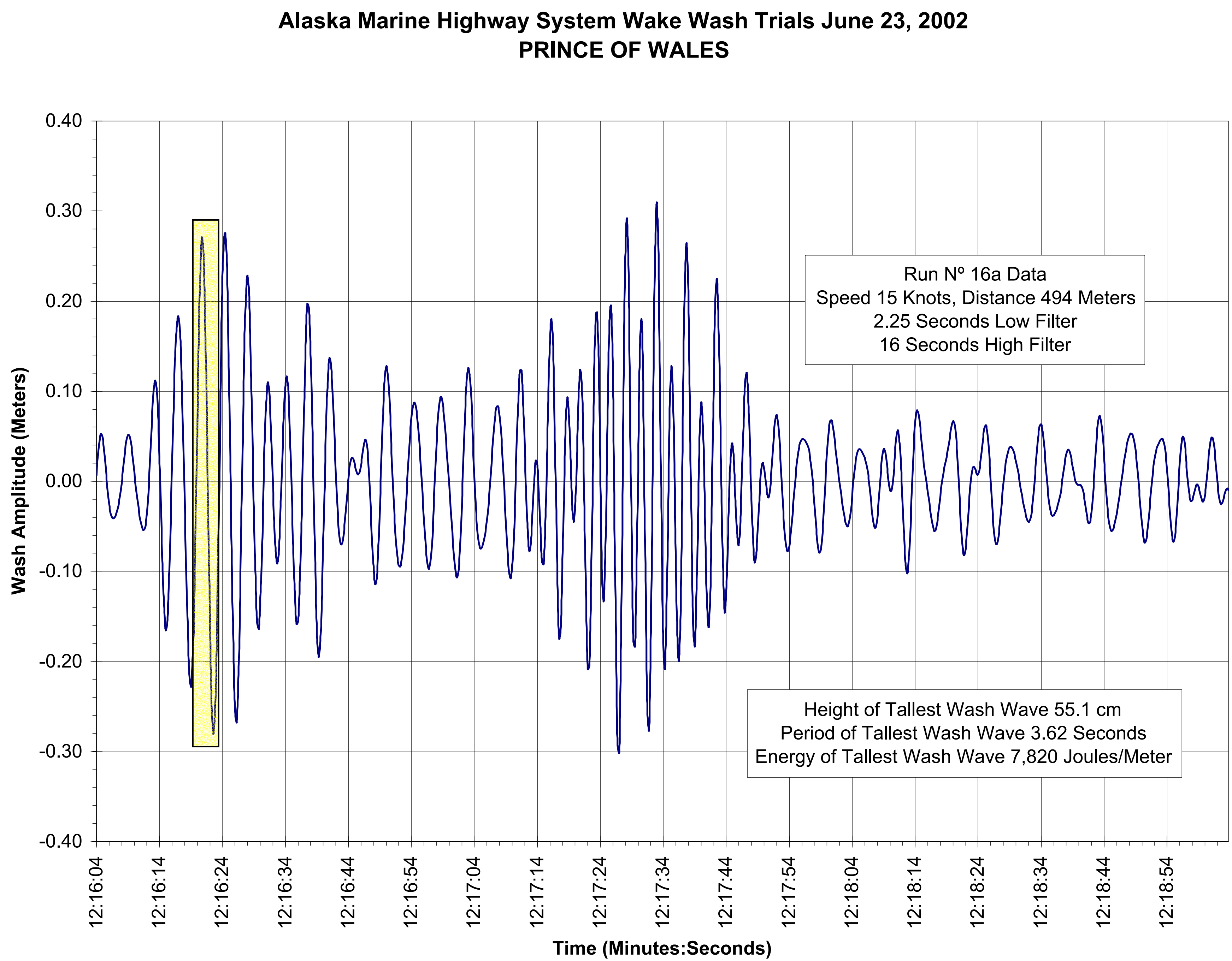
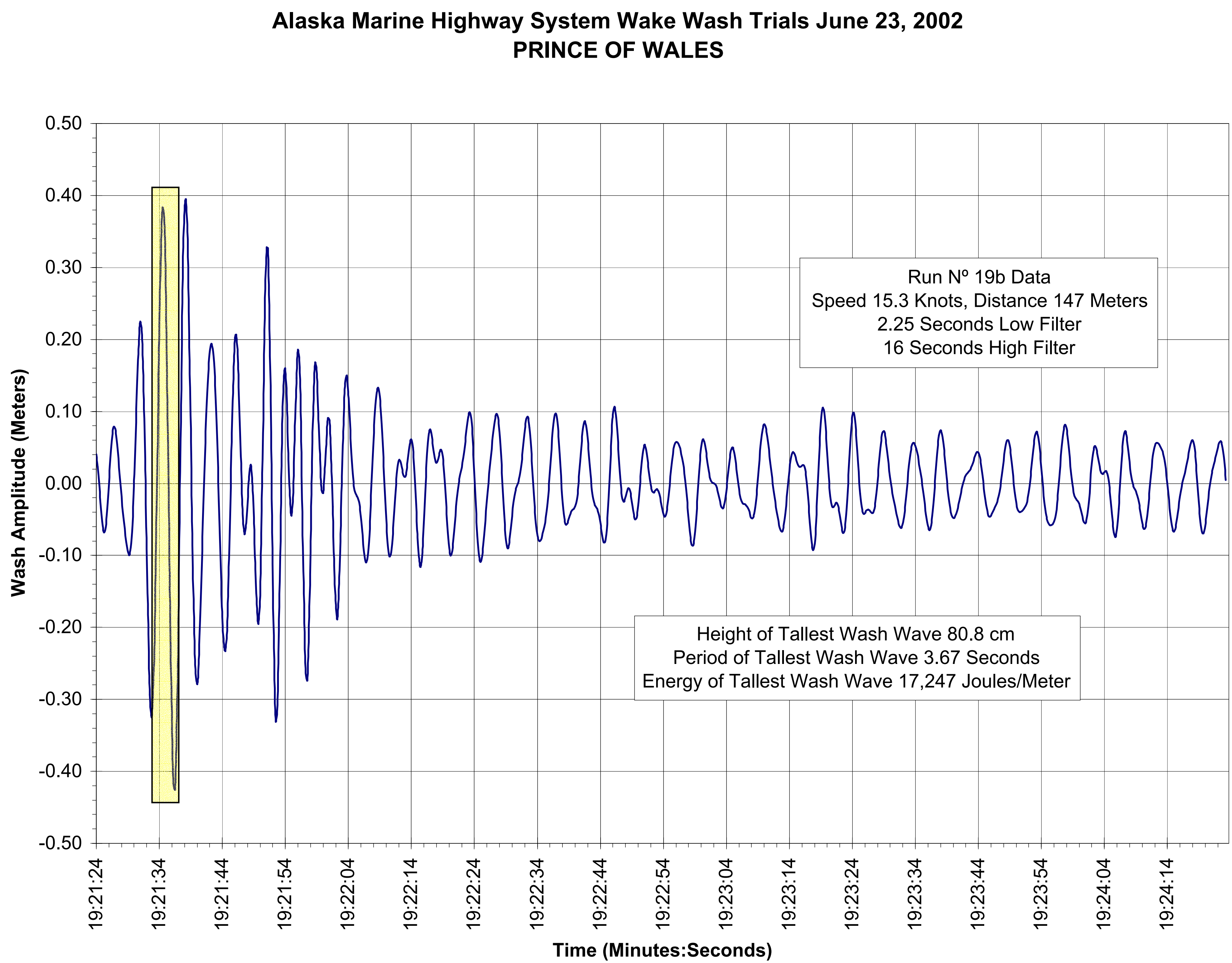
10:22:25
10:22:35



Alaska Marine Highway System Wake Wash Trials June 23, 2002
PRINCE OF WALES
Run Nº 16a Data
Speed 15 Knots, Distance 494 Meters
2.25 Seconds Low Filter
16 Seconds High Filter
Height of Tallest Wash Wave 55.1 cm
Period of Tallest Wash Wave 3.62 Seconds
Energy of Tallest Wash Wave 7,820 Joules/Meter
Wash Amplitude (Meters)
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
12:16:04
12:16:14
12:16:24
12:16:34
12:16:44
12:16:54
12:17:04
12:17:14
12:17:24
12:17:34
12:17:44
12:17:54
12:18:04
12:18:14
12:18:24
12:18:34
12:18:44
12:18:54
Time (Minutes:Seconds)

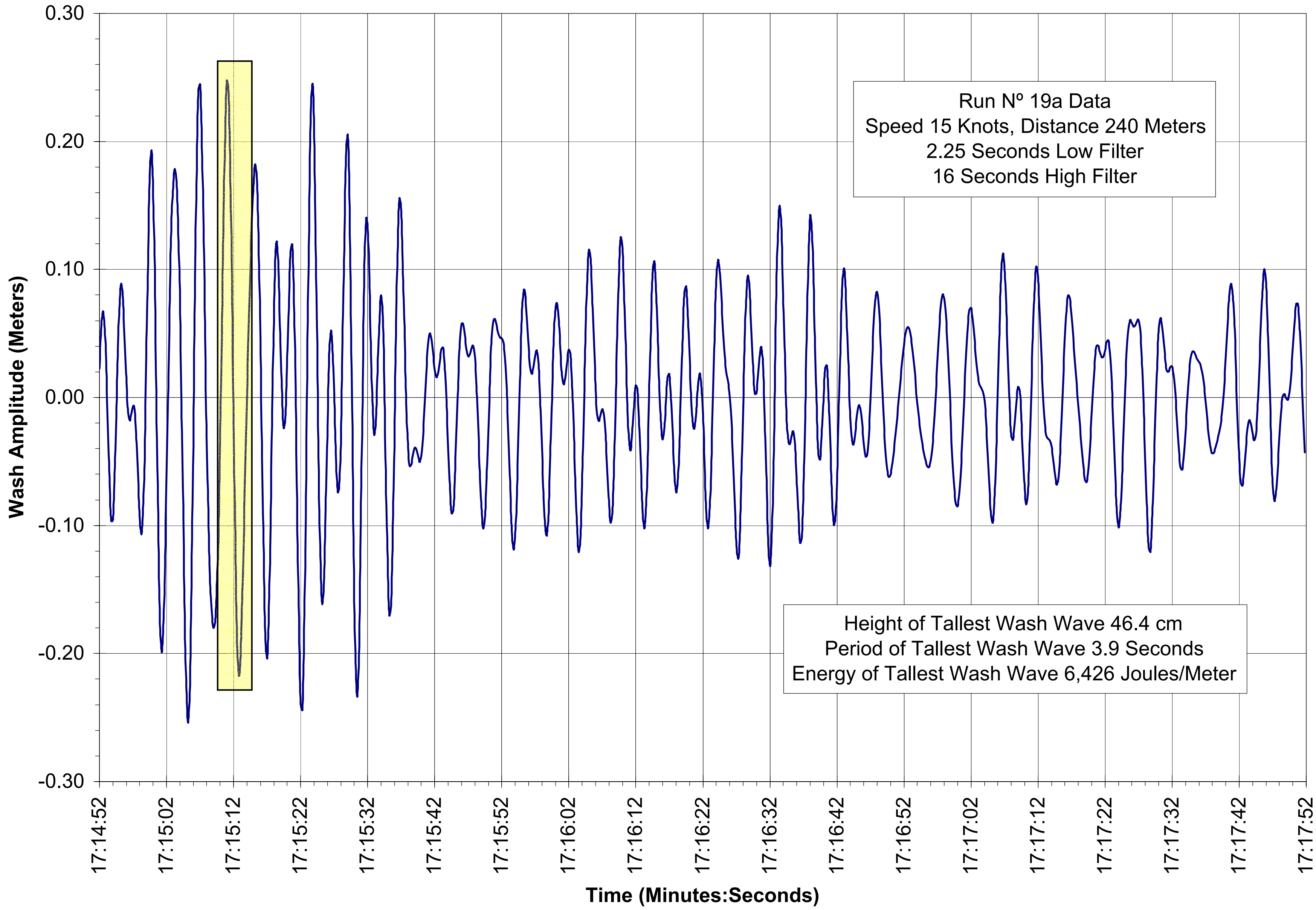
SAMPLE NUMERICAL DATA -- RUN 19b

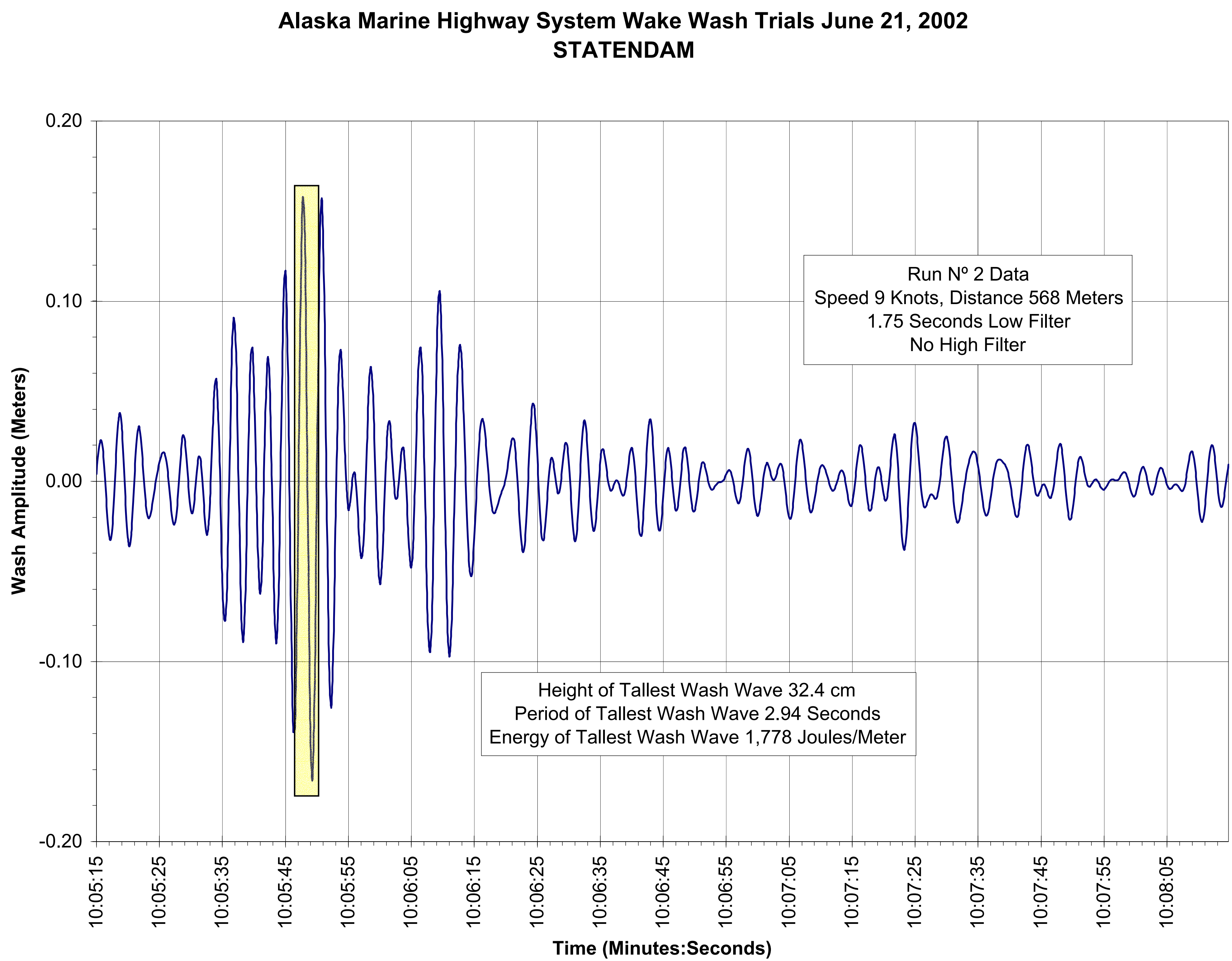
Wave Nº	Up Cross Time	Period Seconds	Height Meters	Energy Joules/Met
1	19:21:26.26	4.006	0.178	1,000
2	19:21:30.26	3.608	0.550	7,730
3	**19:21:33.87**	**3.671**	**0.808**	**17,247**
4	19:21:37.54	3.824	0.673	12,998
5	19:21:41.37	4.211	0.427	6,340
6	19:21:45.58	2.861	0.276	1,226
7	19:21:48.44	2.127	0.221	433
8	19:21:50.57	3.052	0.658	7,923
9	19:21:53.62	1.902	0.222	349
10	19:21:55.52	2.920	0.459	3,530
11	19:21:58.44	1.927	0.263	506
12	19:22:00.37	2.855	0.280	1,251
13	19:22:03.22	4.734	0.260	2,963
14	19:22:07.96	3.876	0.235	1,623
15	19:22:11.83	4.684	0.177	1,355
16	19:22:16.52	5.247	0.175	1,660
17	19:22:21.76	4.721	0.209	1,906
18	19:22:26.48	4.672	0.187	1,491
19	19:22:31.16	4.972	0.172	1,436
20	19:22:36.13	4.653	0.154	1,002
21	19:22:40.78	4.874	0.168	1,321
22	19:22:45.66	4.888	0.156	1,146
23	19:22:50.54	4.728	0.100	440
24	19:22:55.27	4.538	0.144	838
25	19:22:59.81	4.562	0.096	374
26	19:23:04.37	4.839	0.098	442
27	19:23:09.21	4.858	0.149	1,030
28	19:23:14.07	4.720	0.136	806
29	19:23:18.79	4.767	0.173	1,340
30	19:23:23.56	4.643	0.140	827
31	19:23:28.20	4.770	0.134	805
32	19:23:32.97	4.382	0.121	553
33	19:23:37.35	4.491	0.122	590
34	19:23:41.84	5.980	0.090	565
35	19:23:47.82	4.604	0.100	417
36	19:23:52.43	4.610	0.130	709
37	19:23:57.04	4.965	0.136	899
38	19:24:02.00	4.743	0.126	703
39	19:24:06.74	4.768	0.136	820
40	19:24:11.51	5.100	0.123	777



Alaska Marine Highway System Wake Wash Trials June 23, 2002
PRINCE OF WALES
Run Nº 19b Data
Speed 15.3 Knots, Distance 147 Meters
2.25 Seconds Low Filter
16 Seconds High Filter
Height of Tallest Wash Wave 80.8 cm
Period of Tallest Wash Wave 3.67 Seconds
Energy of Tallest Wash Wave 17,247 Joules/Meter
Wash Amplitude (Meters)
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
Time (Minutes:Seconds)
19:21:24
19:21:34
19:21:44
19:21:54
19:22:04
19:22:14
19:22:24
19:22:34
19:22:44
19:22:54
19:23:04
19:23:14
19:23:24
19:23:34
19:23:44
19:23:54
19:24:04
19:24:14

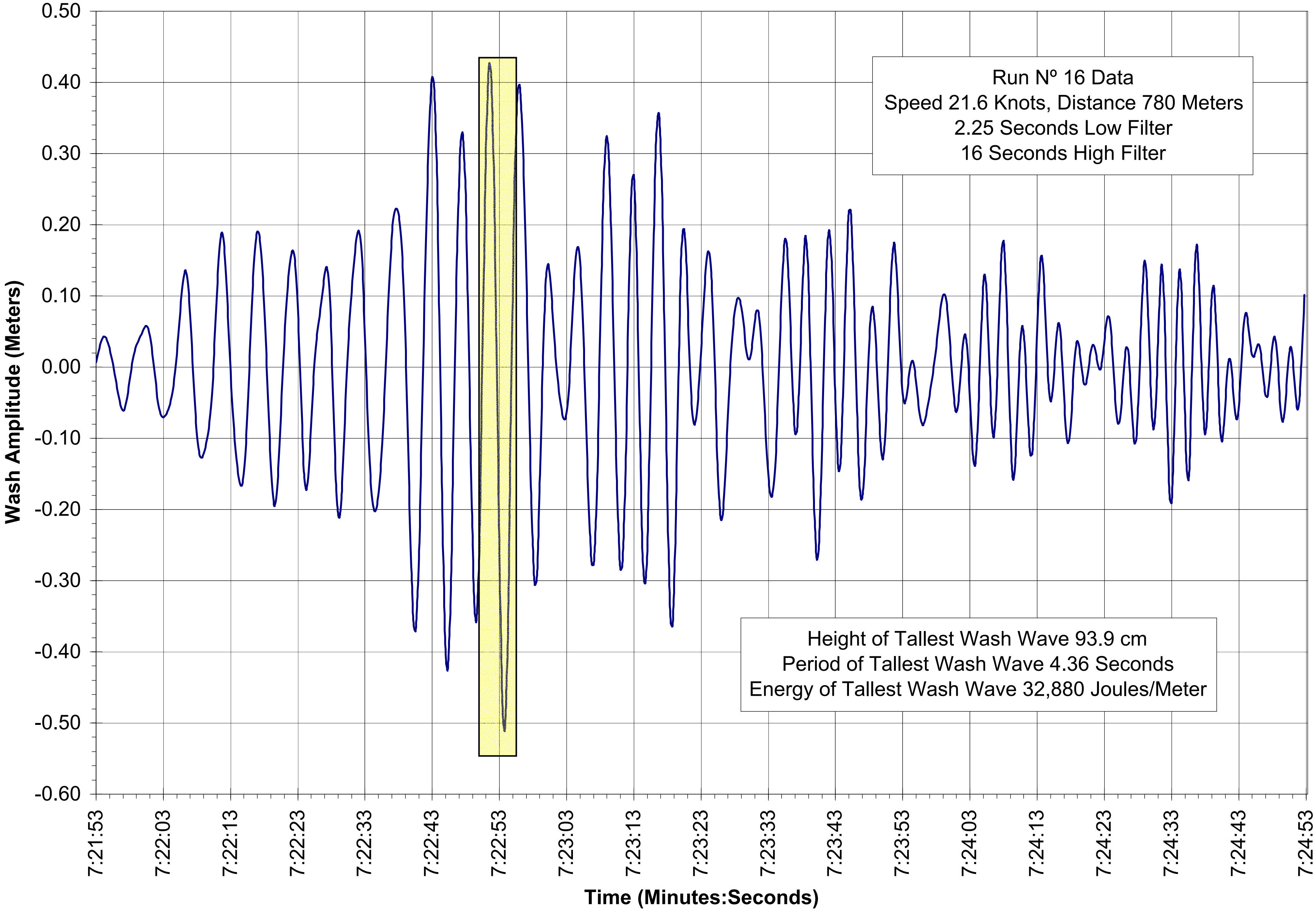
Alaska Marine Highway System Wake Wash Trials June 23, 2002
PRINCE OF WALES

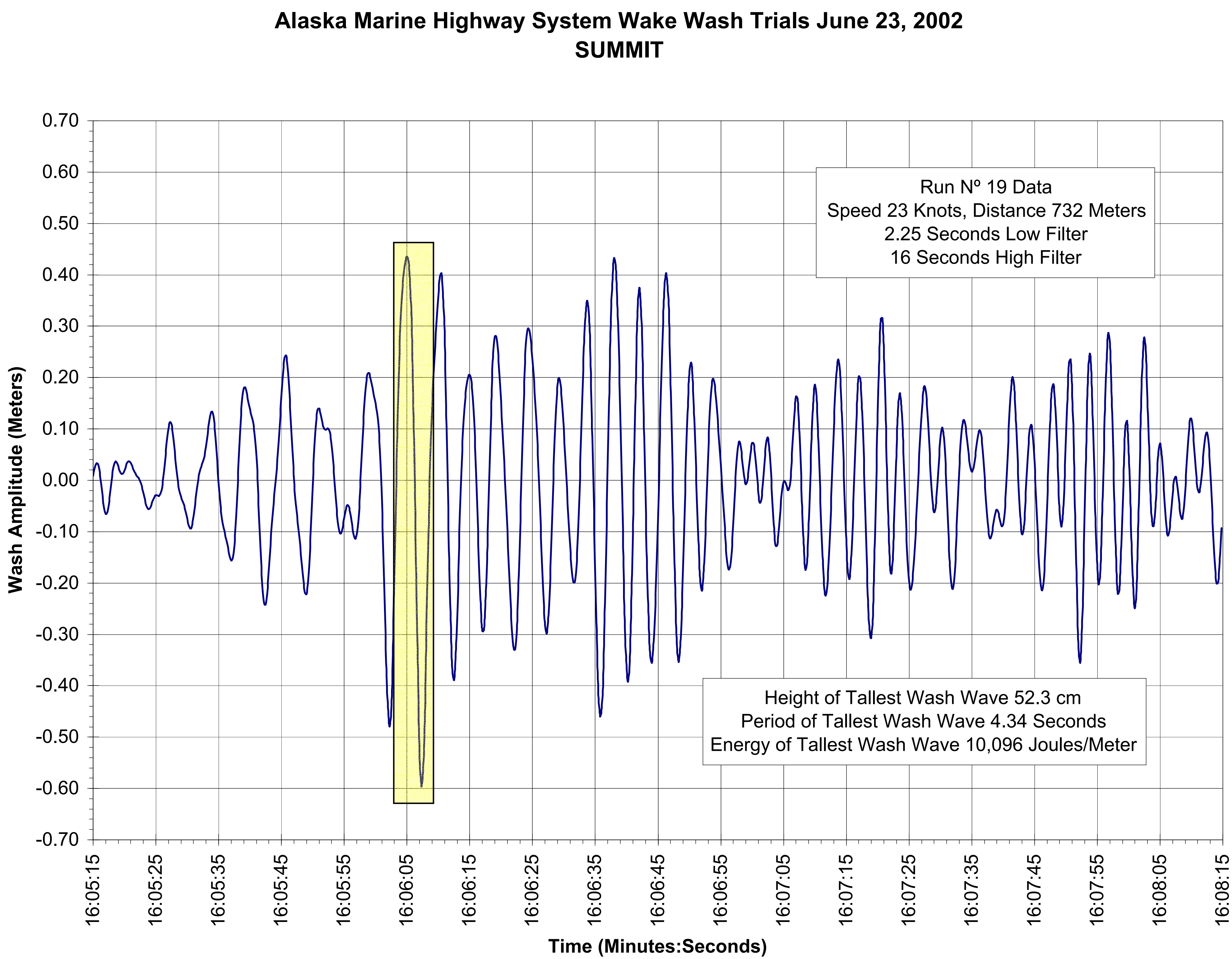




Alaska Marine Highway System Wake Wash Trials June 21, 2002
STATENDAM
Wash Amplitude (Meters)
0.20
0.10
0.00
-0.10
-0.20
Run Nº 2 Data
Speed 9 Knots, Distance 568 Meters
1.75 Seconds Low Filter
No High Filter
Height of Tallest Wash Wave 32.4 cm
Period of Tallest Wash Wave 2.94 Seconds
Energy of Tallest Wash Wave 1,778 Joules/Meter
10:05:15
10:05:25
10:05:35
10:05:45
10:05:55
10:06:05
10:06:15
10:06:25
10:06:35
10:06:45
10:06:55
10:07:05
10:07:15
10:07:25
10:07:35
10:07:45
10:07:55
10:08:05
Time (Minutes:Seconds)

Alaska Marine Highway System Wake Wash Trials June 23, 2002
SUMMIT





Alaska Marine Highway System Wake Wash Trials June 23, 2002
SUMMIT
Run Nº 19 Data
Speed 23 Knots, Distance 732 Meters
2.25 Seconds Low Filter
16 Seconds High Filter
Height of Tallest Wash Wave 52.3 cm
Period of Tallest Wash Wave 4.34 Seconds
Energy of Tallest Wash Wave 10,096 Joules/Meter
Wash Amplitude (Meters)
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
-0.70
16:05:15
16:05:25
16:05:35
16:05:45
16:05:55
16:06:05
16:06:15
16:06:25
16:06:35
16:06:45
16:06:55
16:07:05
16:07:15
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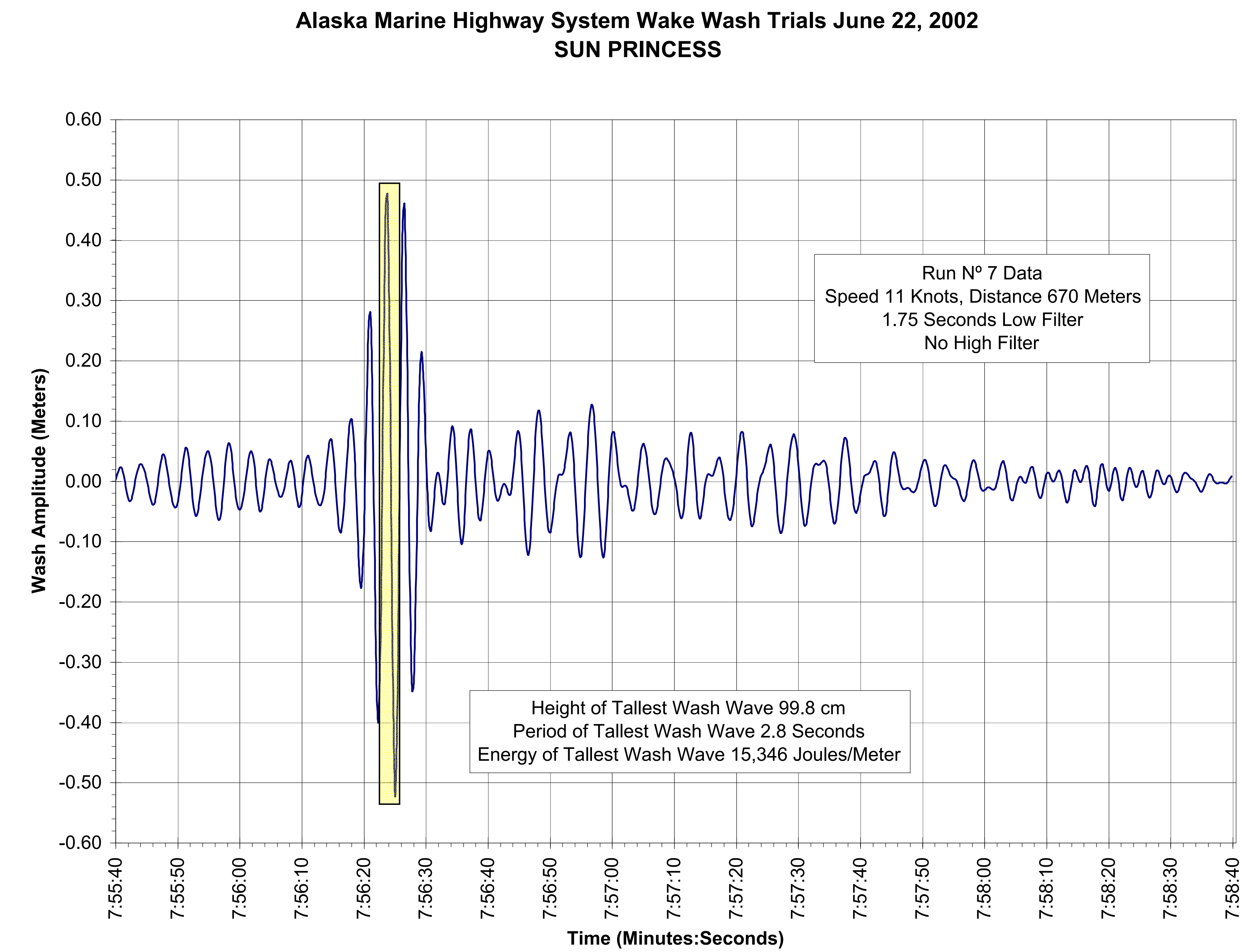
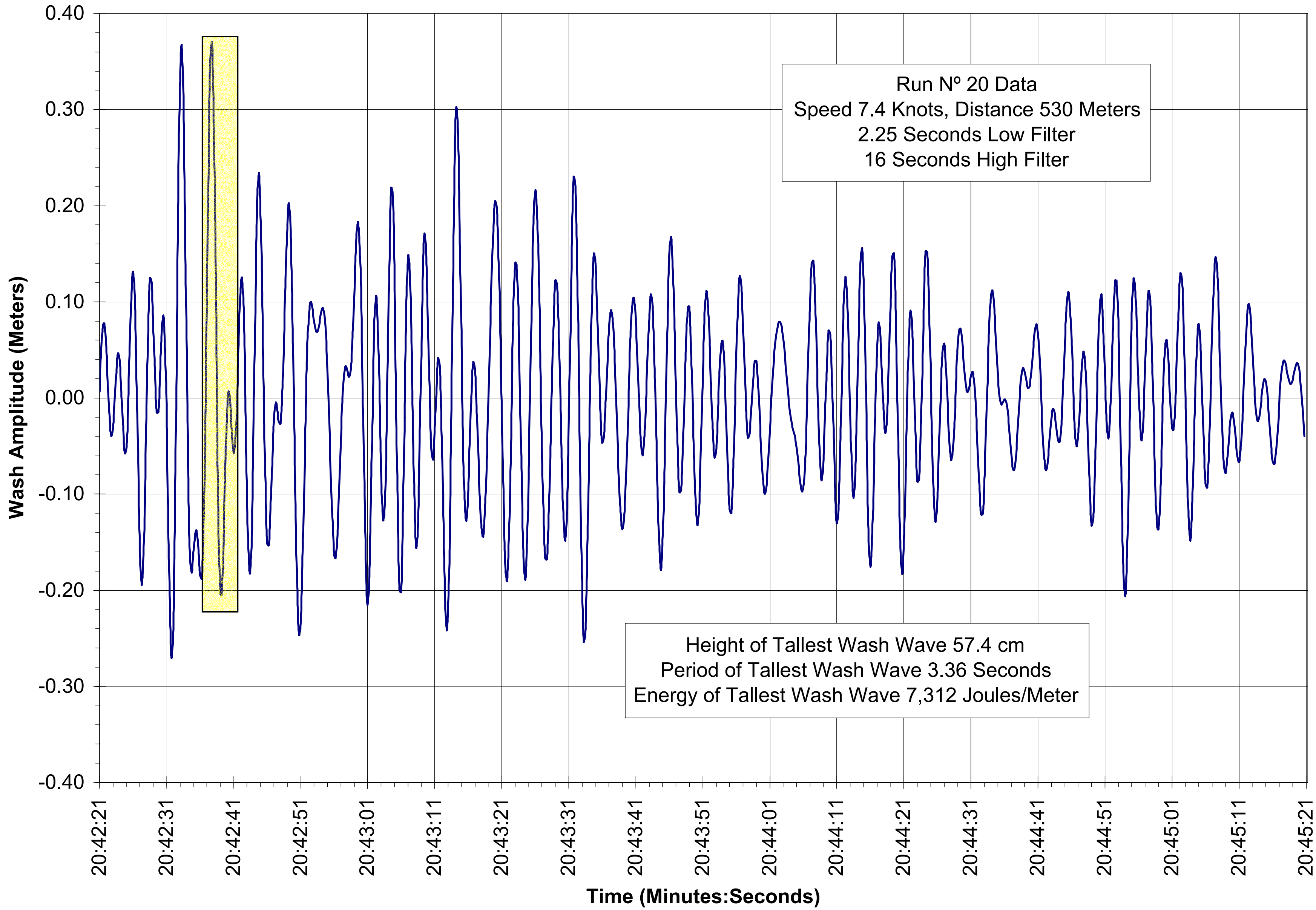
16:07:45
16:07:55
16:08:05
16:08:15
Time (Minutes:Seconds)

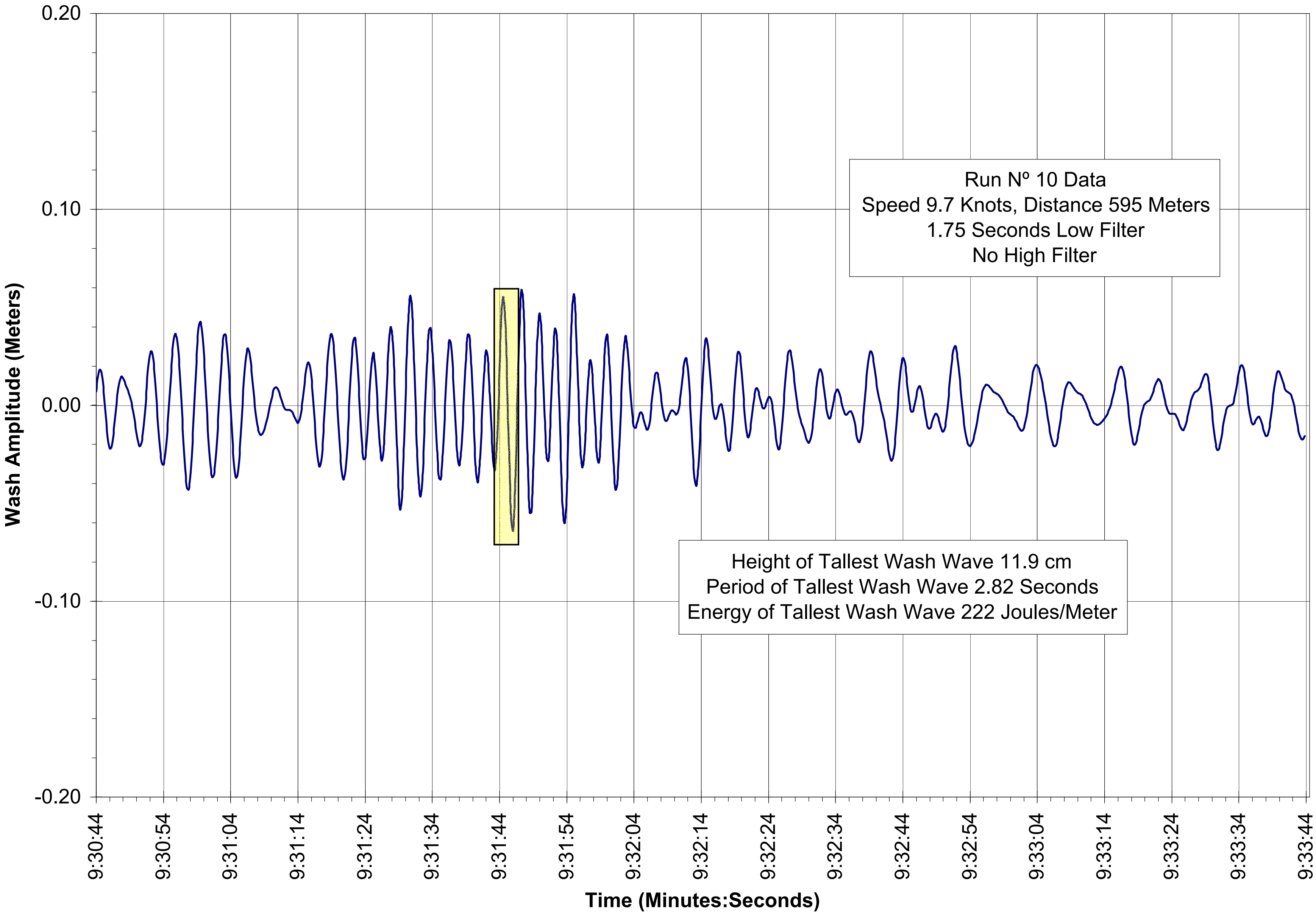


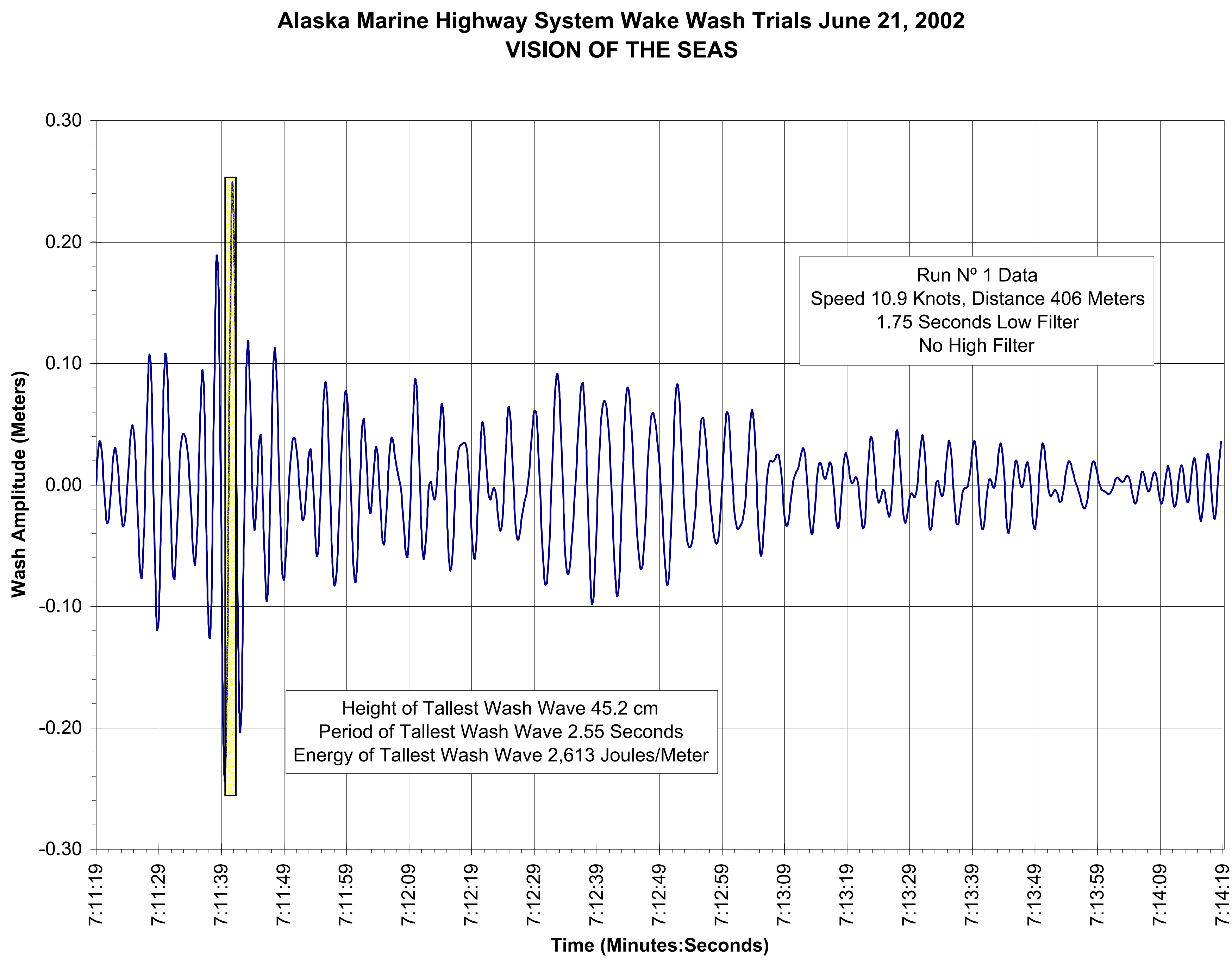
Alaska Marine Highway System Wake Wash Trials June 22, 2002
SUN PRINCESS
Wash Amplitude (Meters)
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
-0.60
Run Nº 7 Data
Speed 11 Knots, Distance 670 Meters
1.75 Seconds Low Filter
No High Filter
Height of Tallest Wash Wave 99.8 cm
Period of Tallest Wash Wave 2.8 Seconds
Energy of Tallest Wash Wave 15,346 Joules/Meter
7:55:40
7:55:50
7:56:00
7:56:10
7:56:20
7:56:30
7:56:40
7:56:50
7:57:00
7:57:10
7:57:20
7:57:30
7:57:40
7:57:50
7:58:00
7:58:10
7:58:20
7:58:30
7:58:40
Time (Minutes:Seconds)

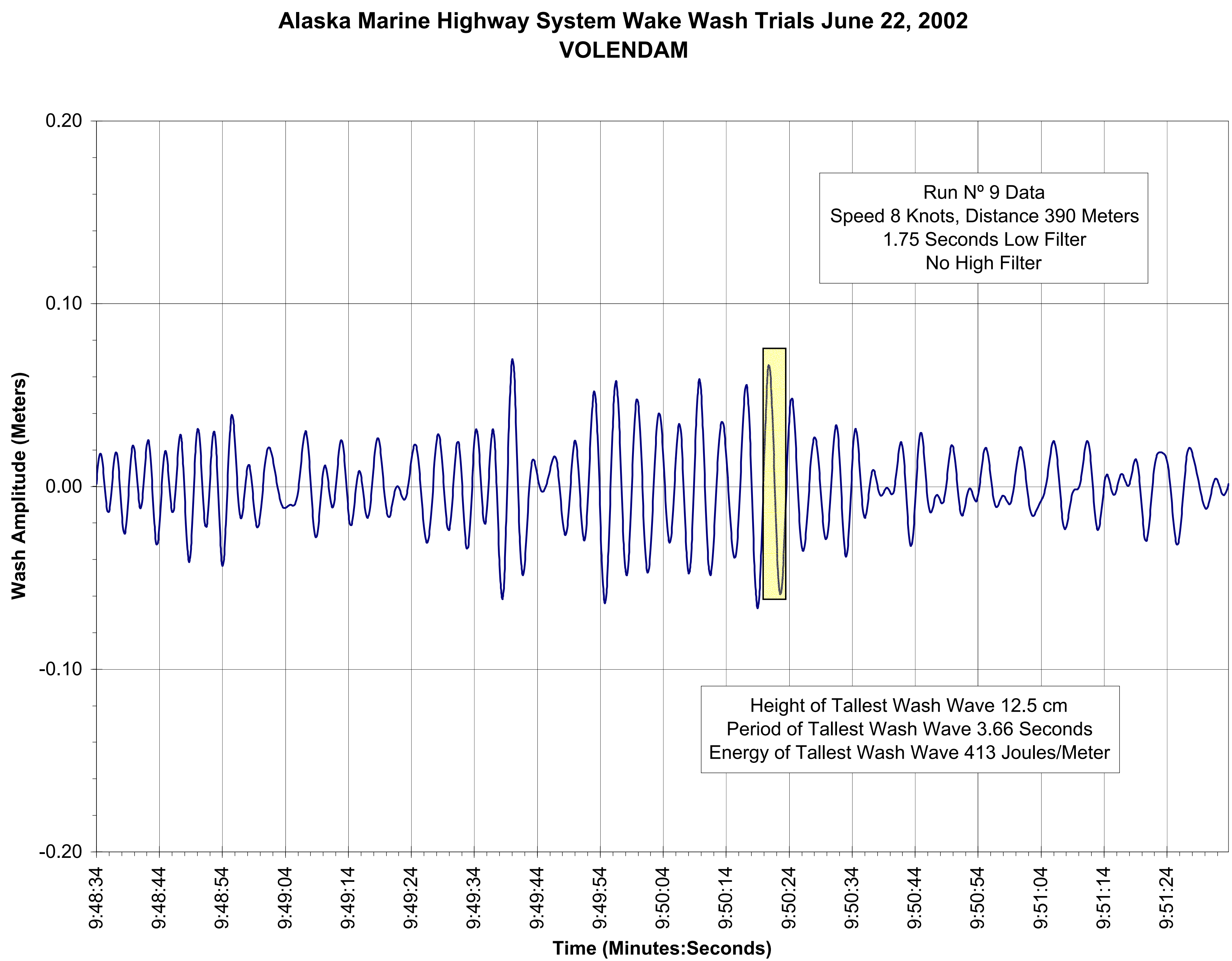
Alaska Marine Highway System Wake Wash Trials June 23, 2002
TAKU



Alaska Marine Highway System Wake Wash Trials June 22, 2002
UNIVERSE EXPLORER




Alaska Marine Highway System Wake Wash Trials June 21, 2002
VISION OF THE SEAS
Run Nº 1 Data
Speed 10.9 Knots, Distance 406 Meters
1.75 Seconds Low Filter
No High Filter
Height of Tallest Wash Wave 45.2 cm
Period of Tallest Wash Wave 2.55 Seconds
Energy of Tallest Wash Wave 2,613 Joules/Meter
Wash Amplitude (Meters)
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
7:11:19
7:11:29
7:11:39
7:11:49
7:11:59
7:12:09
7:12:19
7:12:29
7:12:39
7:12:49
7:12:59
7:13:09
7:13:19
7:13:29
7:13:39
7:13:49
7:13:59
7:14:09
7:14:19
Time (Minutes:Seconds)


Alaska Marine Highway System Wake Wash Trials June 22, 2002
VOLENDAM
Run Nº 9 Data
Speed 8 Knots, Distance 390 Meters
1.75 Seconds Low Filter
No High Filter
Height of Tallest Wash Wave 12.5 cm
Period of Tallest Wash Wave 3.66 Seconds
Energy of Tallest Wash Wave 413 Joules/Meter
Wash Amplitude (Meters)
0.20
0.10
0.00
-0.10
-0.20
9:48:34
9:48:44
9:48:54
9:49:04
9:49:14
9:49:24
9:49:34
9:49:44
9:49:54
9:50:04
9:50:14
9:50:24
9:50:34
9:50:44
9:50:54
9:51:04
9:51:14
9:51:24
Time (Minutes:Seconds)

Alaska Marine Highway System Wake Wash Trials June 22, 2002
VOLENDAM